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Effigy Mounds National Monument

Paleontological Resource Inventory (Public Version)



An example of a fossiliferous Platteville Formation stone at Effigy Mounds National Monument, featuring numerous crinoid columnals (the circular features) as well as some brachiopod shells, shell cross-sections, and horn coral cross-sections. There are also clusters of calcite crystals representing cavity fills, which are post-depositional features.

NPS / JUSTIN TWEET

Effigy Mounds National Monument: Paleontological resource inventory (public version)

Science Report NPS/SR—2025/230

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Contents

Page

Figures....vi
Tables....ix
Appendices....x
Abstract....xi
List of Terms or Acronyms....xii
Acknowledgments....xxv
Introduction....1
Significance of Paleontological Resources at EFMO....3
Purpose and Need....4
Project Objectives....4
History of Paleontological Work at EFMO....5
Summary of 2023–2024 Paleontological Work at EFMO....6
Geology....7
Geologic History....7
Geologic Formations....15
Jordan Formation (Upper Cambrian)....15
Prairie du Chien Group (Lower Ordovician)....18
St. Peter Sandstone (Middle–Upper Ordovician)....24
Glenwood Formation (Upper Ordovician)....27
Platteville Formation (Upper Ordovician)....29
Galena Group: Decorah Formation (Upper Ordovician)....33
Galena Group: Dunleith Formation (Upper Ordovician)....35
Quaternary Rocks and Sediments (Pleistocene–Holocene)....36
Taxonomy....38
Fossil Plants....38
Fossil Invertebrates....38
Phylum Cnidaria (jellyfish and corals)....39
Phylum Bryozoa (moss animals)....41

Contents (continued)

Page

Phylum Brachiopoda (lamp shells) 42
Phylum Mollusca: Class Bivalvia (clams, oysters, etc.) 50
Phylum Mollusca: Class Cephalopoda (octopuses, squids, nautiloids, etc.) 52
Phylum Mollusca: Class Gastropoda (snails) 54
Phylum Arthropoda (arachnids, crustaceans, insects, etc.) 61
Phylum Echinodermata (sea stars, brittle stars, sea lilies, sea urchins, etc.) 65
Other Invertebrates 69
Ichnofossils 71
Other Fossils 74
Fossil Localities 75
Paleontological Localities Within EFMO 75
Paleontological Localities Near EFMO 75
Cultural Resource Connections 76
Museum Collections and Paleontological Archives 77
Museum Collections and Curation 77
EFMO Collections 77
Collections in Other Repositories 81
Archives 81
NPS Paleontology Archives 81
E&R Files 81
Park Paleontological Research 83
Current and Recent Research 83
Paleontological Research Permits 83
Interpretation 84
Current Long Range Interpretive Plan 84
Recommended Interpretive Themes 85
I. General Paleontological Information 85
II. Fossils of EFMO 85

Contents (continued)

Page

III. Caves and Fossil Resources....85
IV. Further Interpretation Themes....85
Paleontological Resource Management and Protection....87
National Park Service Policy....87
Baseline Paleontology Resource Data Inventories....89
Paleontological Resource Monitoring....89
Foundation Documents and Resource Stewardship Strategies....91
Geologic Maps....91
Paleontological Resource Potential Maps....92
Paleontological Resource Management Recommendations....94
Literature Cited....96

Figures

Page

Figure 1. Park map of EFMO....2

Figure 2. A simplified paleogeographic reconstruction of the late Middle Ordovician, approximately the time of the deposition of the St. Peter Sandstone. 7

Figure 3. Thoroughly brecciated beds in the Prairie du Chien Group, Heritage Addition. 9

Figure 4. An undercut outcrop of the Prairie du Chien Group in the Heritage Addition.....10

Figure 5. Schematic stratigraphic column of EFMO bedrock formations, with common fossils seen in the monument. 12

Figure 6. Geologic map of EFMO (North and South Units and Heritage Addition), Iowa.....13

Figure 7. Geologic map of EFMO (Sny Magill Unit), Iowa.....14

Figure 8. An outcrop of Jordan Formation near the South Unit trailhead. 16

Figure 9. A heavily burrowed shed block of the Jordan Formation.....18

Figure 10. A typical bluff-forming outcrop of the Prairie du Chien Group near the South Unit trailhead. 19

Figure 11. A large rockslide.....21

Figure 12. A shed block. 23

Figure 13. Knickpoints in the St. Peter Sandstone at EFMO, Heritage Addition.....25

Figure 14. A steep St. Peter Sandstone bluff in the South Unit. 26

Figure 15. Part of the St. Peter slope break in the southern South Unit.....26

Figure 16. A series of Platteville Formation “natural stairs”. 29

Figure 17. The Platteville Formation is also exposed in ravine walls.....30

Figure 18. A typical Platteville Formation hash plate featuring innumerable shell fragments.....32

Figure 19. A view of Founders Pond. 37

Figure 20. The unusual outline on the right, indicated by a red arrow, is a cross-section through a strongly ribbed brachiopod with a central depression (sulcus), probably a large *Rostricellula* (see below). 39

Figure 21. A selection of Platteville Formation horn corals observed in EFMO.....40

Figure 22. A large stem-like bryozoan fragment (indicated by a red arrow) among brachiopod shells of varying completeness. 42

Figure 23. Various aspects of strophomenid brachiopods observed in EFMO.....44

Figures (continued)

Page

Figure 24. The relatively large triangular shell indicated by a red arrow is attributed to *Camerella*. 45

Figure 25. *Hesperorthis*. 46

Figure 26. The large central shell is *Doleroides*. 47

Figure 27. *Rostricellula*. 48

Figure 28. A fairly typical surface with shells of several brachiopods, including *Sowerbyella* highlighted near the lower right corner. 49

Figure 29. Various fossils. 50

Figure 30. Several shells are visible in cross-section. 51

Figure 31. A likely cyrtodontid bivalve. 52

Figure 32. This complex hash includes several noteworthy fossils. 53

Figure 33. This fossil is most likely a small weathered orthocone but is also very similar to a partial crinoid stem. 54

Figure 34. A partial gastropod cross-section in chert. 55

Figure 35. Three examples of *Hormotoma* are indicated by red arrows. 56

Figure 36. Two views of *Hormotoma* cross-sections. 57

Figure 37. A large *Clathrospira* (outlined in red), partially covered in mud. 58

Figure 38. A cross-section of a small planispiral or nearly planispiral gastropod. 59

Figure 39. This cross-section represents a bellerophontid gastropod. 60

Figure 40. Examples of undetermined gastropod cross-sections. 61

Figure 41. Small trilobite pygidia are indicated by red arrows. 62

Figure 42. The two strongly curved objects denoted “T” represent trilobite genal spines or similar paired elements. 63

Figure 43. The rib-like features are interpreted as the tops of a heavily weathered series of trilobite thoracic segments. 63

Figure 44. The two associated elliptical objects on the right are interpreted as a partially weathered *Eoleperditia* hinged open, with the concave interior surfaces facing the viewer. 64

Figure 45. Some or all of the four indicated bean-like fossils are likely *Eoleperditia* (some could be small pygidia or cephalons of *Bumastoides* or other illaenid trilobites). 65

Figures (continued)

Page

Figure 46. Three columnals are indicated by red arrows: a large "sprocket" on the left, a smaller "sprocket" in the upper right, and a columnal with a "waist" ridge below it. 66

Figure 47. Numerous columnals of multiple forms are visible in this rock, including simple circular, ridged, and sprocket-like. 67

Figure 48. A short segment of multiple articulated ridged columnals, potentially *Abludoglyptocrinus*. 67

Figure 49. Several columnals are indicated by red arrows, including a five-lobed example in the upper right. 68

Figure 50. Columnals are scattered across this surface, including a five-lobed example indicated by a red arrow. 68

Figure 51. The elongate triangular fossil overlying the right-most strophomenid brachiopod is interpreted as a hyolith steinkern. 69

Figure 52. An enigmatic ringed fossil observed in Prairie du Chien Group rocks. 70

Figure 53. The center of the photo is dominated by what resembles an orthoconic nautiloid with a step-like fold (lower margin paralleled by red line). 71

Figure 54. A heavily burrowed Prairie du Chien Group block. 72

Figure 55. A Prairie du Chien Group block with large trace fossils. 73

Figure 56. A block of Platteville Formation rock with various invertebrate trace fossils. 74

Figure 57. Several fossil cross-sections and molds in chert. 76

Figure 58. A rare fossil, *Scenella radialis*, in the Orr collection at EFMO. 78

Figure 59. Titanothere material from what is now BADL in the Orr collection. 79

Figure 60. A typical drawer in the Orr collection at EFMO, showing the use of tight plastic bags and some crowding of specimens. 80

Figure 61. The touch-table fossils available in the visitor center, November 2023. 84

Figure 62. Map indicating paleontological potential of geologic map units in EFMO. 93

Figure 63. Geologic time scale. 121

Tables

Page

Table 1. Summary of EFMO stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. 15

Appendices

Page

Appendix A: Paleontological Species 107

Appendix B: Repository Contact Information 113

Appendix C: Paleontological Resource Law and Policy 114

Appendix D: Geologic Time Scale 120

Abstract

Effigy Mounds National Monument (EFMO) in northeastern Iowa was proclaimed on October 25, 1949, to protect a significant concentration of Native American burial mounds, many of which were built in the shapes of animals such as bears. Many of these effigy mounds are found atop commanding bluffs flanking the Yellow River at its junction with the Mississippi River. The geology of the monument has not been a central interest in its history, but the rocks contain evidence of millions of years of shallow marine life from the early Paleozoic. Paleozoic fossils were first documented at what is now EFMO in the mid-19th century, with few other reports. This inventory is the first report to focus on the paleontological resources of EFMO, documenting the scope, significance, distribution, and management issues associated with these non-renewable resources. It is based on two field visits that took place in July and November 2023.

The bedrock geology exposed within EFMO includes several rock formations dating from between roughly 490 and 450 million years ago, from the end of the Cambrian into the Late Ordovician. These formations capture parts of two major cycles of marine transgression and regression, with a depositional hiatus between them. These rocks were deposited in and near shallow continental seas at a time when the Upper Midwest was at tropical latitudes south of the equator. A variety of fossils have been observed in the Jordan Formation (late Cambrian age), Prairie du Chien Group (Early Ordovician), and Platteville Formation (Late Ordovician). Most of the fossils in the two older units are burrows and other trace fossils. The Platteville Formation includes fossils of a much broader array of life. More than two dozen distinct fossil forms, most identifiable to a genus, have been recognized from the Platteville Formation at EFMO. The fossils belong to a typical Platteville assemblage of horn corals, bryozoans, brachiopods, bivalves, nautiloids, gastropods, trilobites, ostracodes, crinoids, and others. EFMO also has a small Holocene record from Founders Pond that is useful for reconstructing the monument's ecology during the time when the mounds were built.

In addition to the above, this report documents cultural associations with paleontological resources and the monument's museum collections (including the extensive fossil collections of foundational figure Ellison Orr). Discussion and recommendations for research, interpretation, and paleontological resource management are included in this report.

List of Terms or Acronyms

Acritarch: A “wastebasket” term for organic microfossils that cannot be assigned to another group.

Adit: A horizontal or nearly horizontal passage to an underground mine, used for a variety of purposes.

Aglaspidid: A member of the order Aglaspidida, an extinct group of arthropods resembling a cross between a trilobite and a horseshoe crab, known from the Cambrian and Ordovician.

Alluvial (adjective), **alluvium** (noun)**:** A general term for deposits of unconsolidated terrestrial sediment transported by unconfined water (i.e., not in a channel) and not attributed to a more specific process (i.e., not fluvial, glacial, or lacustrine).

Angiosperm: A member of the clade Angiospermae, the flowering plants, known from the Cretaceous to the present.

Annulated: A structure with ring-like bands, which can be broad or narrow.

Aragonite: A calcium carbonate mineral used by some organisms, such as mollusks, in shells and other hard parts. It is not as stable as calcite over geologic time and is more susceptible to dissolution or replacement.

Arthropod: A member of the phylum Arthropoda, a diverse group of invertebrates with exoskeletons, segmented bodies, and jointed appendages. Insects, arachnids, and crustaceans are modern examples. Arthropods appeared by the early Cambrian.

Asteroid: A member of the class Asteroidea, a group of echinoderms familiar for their five radiating arms; also known as “sea stars” or “starfish”, asteroids are known from the Ordovician to the present.

Basin (geological)**:** A depression formed by folding and faulting in which sediments are accumulated; former geologic basins can often be identified by rock strata dipping to a central point, a bull’s-eye pattern of rocks in a geologic map with the youngest rocks at the center, or an anomalous area of young rocks at the same elevation as older rocks in the vicinity.

Beak: In shell anatomy, the oldest part of a valve, often forming a point or projection.

Bellerophontid: A member of the order Bellerophontida, an extinct group of mollusks frequently with a planispiral shell and a flaring aperture, known from the Cambrian into the Triassic. Bellerophontids are often classified as gastropods but may be outside of Gastropoda.

Bentonite: A clay that forms from the breakdown of volcanic ash.

Biostratigraphy: Using fossils to identify the relative positions and ages of rocks in a succession.

Bioturbation: Disturbance of sediment by organisms to the extent that sedimentary structures such as bedding are destroyed.

Bivalve: A member of the class Bivalvia, a group of mollusks with two shells; bivalves are also sometimes known as pelecypods, to reduce confusion (the term "bivalve" in a general sense also applies to other groups, such as brachiopods and some arthropods). Modern examples include clams, oysters, mussels, and scallops. Bivalves are known from the Cambrian to the present.

Brachidium: A mineralized structure supporting a brachiopod's lophophore.

Brachiopod: A member of the class Brachiopoda, a group of marine filter-feeding animals with two shells, resembling bivalve mollusks but more closely related to bryozoans. Brachiopods are sometimes known as "lamp shells" because some of them resemble ancient oil lamps and are known from the Cambrian to the present.

Breccia: A rock composed of angular fragments cemented in a fine-grained matrix.

Bryozoan: A member of the phylum Bryozoa, a group of filter-feeding aquatic colonial animals. Bryozoans are sometimes called "moss animals" because they often encrust objects. They are known from the Ordovician to the present.

Calcareous: Mostly or partly composed of calcium carbonate; lime-rich.

Calcite: A mineral made of calcium carbonate, the primary component of limestone and some fossils.

Calcium carbonate: A compound with the chemical formula $CaCO_3$. Calcite is a common form.

Cambrian: The first geologic period of the Paleozoic Era, noted for the abrupt diversification of life ("Cambrian explosion"); approximately 539 to 485 million years ago (Ma).

Carbonate (geology)**:** A general term for minerals containing carbonate ions (CO_3^{-2}), such as calcite and dolomite, and rocks containing these minerals, such as limestone and dolostone.

Carboniferous: Internationally, the fifth geologic period of the Paleozoic Era, usually divided into the Mississippian and Pennsylvanian in North America; approximately 359 to 299 Ma.

Case-hardening: The production of a resistant zone or crust on outcrop surfaces due to weathering.

Cenozoic: A geologic era, dated approximately 66 Ma to the present, noted for the diversification of mammals; the term means "new life".

Cephalon: The head shield of a trilobite.

Cephalopod: A member of the class Cephalopoda, a group of mollusks with a prominent head fringed by tentacles. Examples include squids, octopuses, nautiloids (such as *Nautilus*), and many extinct forms, especially ammonoids. Cephalopods are known from the Cambrian to the present.

Chert: A rock made of microcrystalline silica lacking obvious macroscopic crystals. Flint is a variety of chert found in chalk and marly limestone.

Chitinozoan: A flask-shaped organic-walled microfossil that probably represents some kind of resting cyst or invertebrate egg case.

Chlorophyte: A member of the clade Chlorophyta, a type of green algae.

Cladistics: A biological classification method grouping organisms in groups (clades) based on the proportion of shared measurable derived characteristics (synapomorphies). Cladistics is the most commonly utilized method for classifying organisms.

Clast: A rock fragment of any size. A rock made up of clasts, such as sandstone or shale, is called clastic.

Clubmoss: A type of diminutive evergreen plant that reproduces using spores and resembles a tiny pine tree.

Cnidarian: A member of the phylum Cnidaria, a group of invertebrates noted for capturing prey using stinging cells, known from the Ediacaran to the present. Most fossil cnidarians are corals.

Colluvial (adjective), **colluvium** (noun)**:** Unconsolidated sediment deposits formed by gravity-driven movement, commonly found at the base of topographic highs such as hills.

Columnal: Individual segments of an echinoderm's stalk, particularly crinoids. They resemble rings, doughnuts, sprockets, or gears.

Conifer: A member of the division Pinophyta, including gymnosperm trees such as pines, firs, cypresses, cedars, hemlocks, larches, spruces, and more; non-flowering plants that produce seeds and pollen from cones, known from the Pennsylvanian to the present.

Conodont: A member of the class Conodonta, an extinct group of eel-like chordates known primarily from jaw elements, known from the Cambrian into the Jurassic.

Contact (geology)**:** The horizon or plane where two formations meet.

Conulariid: A member of the clade Conulariida, an extinct group of distant relatives of corals that formed flat-sided conical structures from small, mineralized rods, known from the Ediacaran into the Triassic.

Coprolite: Fossil feces.

Corallite: The dwelling cell of an individual coral animal.

Cornulitid: A member of the order Cornulitida, an extinct group of enigmatic invertebrates that formed millimeter-scale elongate ribbed conical shells, known from the Ordovician into the Pennsylvanian. Cornulitids may have been mollusks or "worms" related to bryozoans, brachiopods, and horseshoe worms.

Cretaceous: The third and last geologic period of the Mesozoic Era, noted for the rise of flowering plants and the extinction of many organisms at the end of the period; approximately 145 to 66 Ma.

Crinoid: A member of the order Crinoidea, a group of echinoderms featuring a cup-like body with feathery tentacular arms, usually but not always attached to a surface with a stalk. Crinoids are also known as sea "lilies" and are known from the Ordovician to the present.

Cyanobacteria: Photosynthetic bacteria, also known informally as "blue-green algae".

Cycadeoid: A member of the plant order Bennettitales, an extinct group of plants known from the Permian to the end of the Cretaceous that combined cycad-like or palm-like foliage, a stout trunk, and flower-like reproductive organs.

Cyclocrinitid: A member of an informal group of enigmatic extinct organisms, possibly algae, known from the Ordovician and Silurian.

Cyclocystoid: A member of the class Cyclocystoidea, an extinct group of echinoderms represented by flat ring-like fossils made of many small elements, known from the Ordovician to the Devonian.

Cystoid: A member of the class Cystoidea, an extinct group of stalked echinoderms similar to crinoids, known from the Ordovician to the Devonian.

Dasycladacean: A member of the family Dasycladaceae, a group of chlorophyte algae that construct mineralized walls, leading to large stony colonies. They are known from the Ordovician to the present.

Debitage: An archeological term for rock debris produced by working stones to produce tools and weapons.

Devonian: The fourth geologic period of the Paleozoic Era; approximately 419 to 359 Ma.

Diagenesis: Physical and chemical alteration to sediments and biological remains after deposition by compaction, fluids, and microbial activity, leading to lithification and fossilization.

Diatom: A kind of algae that secretes cell walls of silica, known from the Jurassic to the present. Diatoms are common microfossils.

Disconformity: An unconformity where the strata above and below the geologic contact are parallel, but the contact itself shows evidence of missing time by erosion or nondeposition.

DOI: Department of the Interior or, in references, digital object identifier.

Dolomite: A mineral made of calcium-magnesium carbonate with the chemical formula $CaMg(CO_3)_2$; the term is also used inaccurately for rock made of dolomite (see dolostone). Most dolomite is formed by the replacement of some of the calcium ions in calcium carbonate by magnesium, a process called dolomitization.

Dolostone: A rock made of dolomite.

Dolomitization: The conversion of calcium carbonate to dolomite by the replacement of calcium ions with magnesium. This process involves recrystallization and is destructive to fossils made of calcium carbonate, although not all such fossils are affected the same way: mollusk shells are more susceptible than brachiopod and bryozoan specimens, which in turn are more susceptible than echinoderm columnals and plates.

Drift (geology)**:** A general term for any deposit of glacial origin.

Echinoderm: A member of the phylum Echinodermata, a group of invertebrates noted for their five-fold symmetry. Sea stars, sea urchins, sea lilies, and sea cucumbers are some examples. Echinoderms are known from the Cambrian to the present.

Echinoid: A member of the class Echinoidea, a group of echinoderms commonly having a globose body covered in spines, also called “sea urchins”. They are known from the Ordovician to the present.

Ediacaran: (Geochronology) The last geologic period of the Neoproterozoic Era; approximately 635 to 539 Ma. It marks the end of the Proterozoic Eon, and the beginning of the Phanerozoic Eon. (Paleontology) A general adjective for soft-bodied, often frond-like organisms that flourished during this period.

Edrioasteroid: A member of the class Edrioasteroidea, an extinct group of echinoderms that resemble a sea star attached to a bulb attached to the sea floor (reflected in the informal name “seated star”), known from the Cambrian into the Permian.

Eolian: A sedimentary process involving the erosion, transport, and deposition of sediments by wind; also used to describe rocks or environments formed or influenced by wind. Loess and sand dunes are features created by eolian processes.

Eurypterid: A member of the order Eurypterida, a group of extinct arthropods often known informally as a “sea scorpion” for their large scorpion-like appendages and general body shape; known from the Ordovician to the end of the Permian.

Facies: A body of rock that is distinct from the surrounding rock, due to specific aspects of depositional processes and environmental setting; facies are often invoked when there are differences within a formation or member that are not suitable for mapping (i.e., not laterally persistent).

Feldspar: A group of alumino-silicate minerals composed of various metal ions, aluminum, silicon, and oxygen. Feldspars are the most common minerals in the Earth's crust.

Float (geology)**:** Eroded material resting on the surface, not attached to an outcrop.

Fluvial: A sedimentary process involving the erosion, transport, and deposition of sediments by confined flowing water; rivers and streams are depositional environments where fluvial processes dominate.

Foraminifera: A member of the subphylum Foraminifera, "shelled amoebas"; "foraminifera" is often used for both singular and plural, although some authorities prefer "foraminiferan" for singular and "foraminiferans" or "foraminifers" for plural, and others use the more informal "foram" and "forams." Foraminifera are well-known as microfossils from their tests, which are usually composed of calcium carbonate or tiny sediment grains (agglutinated). They are known from the Ediacaran to the present.

Formation (geology)**:** Fundamental rock-stratigraphic unit that is mappable, lithologically distinct from adjoining strata, and has definable upper and lower contacts; the basic unit of stratigraphy.

Fossiliferous: A rock or deposit that yields fossils.

Fucoid: In paleontology, a term often used in the 19th and early 20th centuries for fossils thought to be seaweed impressions (after Fucales, the brown algae), but now known to be invertebrate burrows and other trace fossils.

Gastropod: A member of the class Gastropoda, a group of mollusks including snails and slugs (snails without shells), known from the Cambrian to the present.

Graptolite: A member of the subclass Graptolithina, a group of colonial invertebrates that live in bottom-attached or free-floating colonies, known from fossils of Cambrian to Mississippian age and found in the present as pterobranch "worms".

GRD: Geologic Resources Division of the National Park Service.

GRI: Geologic Resources Inventory.

GSRI: Geologic & Soil Resources Inventories.

Hardground: Naturally cemented seafloor; hardening occurred before the seafloor was buried. Hardgrounds were inhabited by assemblages specialized to live on or in the hard surface.

Helcionelloid: A member of the class Helcionelloida, an extinct group of superficially snail-like extinct mollusks known from the Cambrian and Ordovician.

Holocene: The second and most recent epoch of the Quaternary Period, following the Pleistocene and the last glacial maximum; approximately 11,700 years ago to the present.

Holothuroid: A member of the class Holothuroidea, a group of sac-shaped echinoderms also known as "sea cucumbers", with sac-like bodies generally supported by an internal skeletal framework of microscopic, mineralized elements known as ossicles or sclerites, known from the Ordovician to the present.

Holotype: A name-bearing specimen for an organism. Some species are based on multiple specimens, which are called cotypes (outdated; sometimes "co-types") or syntypes.

Horn coral: An extinct solitary coral of the class Rugosa. The name refers to the shape of the coral's skeleton, resembling an animal horn.

Hyolith: A member of the class Hyolitha, an extinct group of animals with elongate triangular shells, apparently close to the ancestry of brachiopods, mollusks, or both, known from the Cambrian to the end of the Permian.

Ichnofossil (also **trace fossil**)**:** Fossilized remains of biological activity of an organism, including root traces, footprints, tracks, burrows, trails, coprolites, and other biogenically produced features.

Ichnogenus, ichnospecies, ichnotaxon: A scientific name used for a trace fossil, existing in parallel to the names used for body fossils.

In situ (geology)**:** When describing fossils, this means found in place at an outcrop.

Jurassic: The second geologic period of the Mesozoic Era; approximately 201 to 145 Ma.

Karst: A characteristic topography of sinkholes, caves, and other features formed by the dissolution of carbonate rocks at or near the surface.

Knickpoint: A sharp change in the slope of a channel's bed, such as at a waterfall.

Lacustrine: A lake as depositional environment or mode of transport.

Laurentia: The relatively stable Precambrian core of the North American continent.

Limestone: A sedimentary rock consisting mainly of calcium carbonate, primarily in the form of the mineral calcite.

Lithified: A sedimentary deposit that has become rock.

Lithology: Physical characteristics of a rock such as texture, grain size, etc., that are used for description and classification by rock type and lithostratigraphic unit (e.g., formation, member, etc.).

Locality: A distinct site, especially one known to field fossils or other unique features.

Loess: A deposit of generally silt-sized wind-blown dust.

Lophophore: The tentacle-bearing feeding organ of brachiopods, bryozoans, and some other groups.

Ma: An abbreviation for "mega-annum," but more easily understood as "million years ago."

Macrofossil: A fossil that can be studied with the naked eye or a hand lens.

(Marine) **Regression** (noun), **regressive** (adjective)**:** A marine retreat, exposing land during a drop in sea level.

(Marine) **Transgression** (noun), **transgressive** (adjective)**:** A marine encroachment, submerging land during a rise in sea level.

Member: A subdivision of a formation.

Microfossil: A fossil, typically 1 mm (0.04 in) or less in size, that must be studied with a microscope.

MISS: Mississippi National River and Recreation Area; may also be given as MNRRA.

Mold: In paleontology, an internal or external impression of an organism left in sediment.

Mollusk: A member of the phylum Mollusca, a diverse group of invertebrates noted for their combination of a muscular foot, a shell, and a mantle that covers the innards and secretes the shell. Examples include bivalves, cephalopods, and gastropods (snails). They are known from the Cambrian to the present.

Monoplacophoran: A member of the class Monoplacophora, a group of shelled mollusks known from the Cambrian to the present. Most monoplacophorans have a cap-like or limpet-like shell, but some extinct forms had planispiral shells.

NAGPRA: Native American Graves Protection and Repatriation Act.

Nautiloid: A member of the subclass Nautiloidea, a group of shelled cephalopod mollusks represented today by species of chambered nautilus, but in the past including various straight (orthoconic) and coiled forms, known from the Cambrian to the present.

NPS: National Park Service.

Ordovician: The second geologic period of the Paleozoic Era, following the Cambrian; approximately 485 to 443 Ma.

Organic: Made of organic compounds (i.e., molecules of carbon, hydrogen, nitrogen, and oxygen); pollen, spores, and cysts, all of which can be fossilized, have organic walls.

Orthocone (noun), **orthoconic** (adjective)**:** A type of nautiloid shell that is straight and gently tapering.

Ostracode or **ostracod:** A member of the class Ostracoda, a group of shelled and generally microscopic crustaceans known informally as "seed shrimp", known from the Ordovician to the present.

Paleozoic: A geologic era, dated approximately 539 to 252 Ma, noted for the diversification of invertebrates and the appearance of vertebrates and land plants; the term means "early life".

Palynomorph: An organic-walled microfossil. Pollen and spores are common examples; other types include tests of some microorganisms and jaw elements of worms.

Paracrinoid: A member of the class Paracrinoidea, an extinct group of stalked echinoderms that somewhat resembled crinoids, known from the Ordovician to the Silurian.

Paratype: A specimen of an organism that helps define it, but which is not a name-bearing specimen.

Parting: A thin layer of softer rock between thicker beds of harder rock.

Peat: Partially decayed vegetation.

Phanerozoic: The fourth and final geologic eon of Earth's history; approximately 539 Ma to the present.

Phosphate (geology)**:** A general term for minerals containing phosphate (PO_4^{-3}), such as apatite, found in bones, teeth, and some shells (the phosphatic shells of some inarticulate brachiopods, for example).

Photic zone: The uppermost layer of a body of water, which receives enough sunlight for photosynthetic plankton.

Planispiral: A shell coiled in a flat plane, like a *Nautilus* shell.

Pleistocene: The older of two epochs in the Quaternary Period, noted for ice ages; approximately 2.58 Ma to 11,700 years ago.

Polyplacophoran: A member of the class Polyplacophora, a group of mollusks with ovoid bodies protected by a series of plate-like shells, known from the Cambrian to the present. Chitons are modern polyplacophorans.

Precambrian: Geologic time before the Cambrian, before approximately 539 Ma.

PRPA: Paleontological Resources Preservation Act (2009).

Pseudofossil: An object or feature that resembles a fossil but is actually not of organic origin.

Pygidium: The "tail" section of a trilobite. This section detached readily when the exoskeleton was shed, so pygidia are common fossils.

Quartz: A common mineral composed of silica, chemical formula SiO_2.

Quaternary: The most recent geologic period, third and last in the Cenozoic Era, noted for multiple ice ages; approximately 2.58 Ma to the present.

Receptaculitid: A member of the family Receptaculitidae or Receptaculitaceae, an extinct family of "sunflower corals," known from the Ordovician to the end of the Permian. The evolutionary relationships of receptaculitids are unclear; they may be chlorophyte green algae.

Red algae: A member of the division Rhodophyta, a diverse and abundant group of mostly marine algae outside of green plants, with an evolutionary history extending well into the Precambrian.

Reworked: A fossil that has been eroded from an older rock unit and redeposited in a younger unit.

Rhombiferan: A member of the order Rhombifera, an extinct group of cystoid echinoderms named for distinctive pores on their surfaces, known from the Cambrian to the Devonian.

Rostroconch: A member of the class Rostroconchia, an extinct group of mollusks that had "taco"-like single folded shells, known from the Cambrian to the end of the Permian.

Rugose coral: A member of the subclass Rugosa, an extinct group of corals, known from the Ordovician to the end of the Permian. Rugose corals included both colonial and solitary forms, with the solitary forms known as horn corals.

SACN: St. Croix National Scenic Riverway.

Sauk sequence: The first major sea-level cycle of the Phanerozoic, occurring during the Cambrian and Early Ordovician, resulting in inland seas depositing sediments across the craton of North America.

Scenellid: A member of the superfamily Scenelloidea, an extinct group of invertebrates with pyramidal conical shells, known from the Ordovician. Scenellids were probably mollusks, and possibly monoplacophorans or gastropods.

Scolecodont: A jaw element of a bristle worm, a common microfossil.

Septum: In corals, a septum (plural: septa) is a vertical plate in a corallite; in shelled cephalopods, the wall between chambers.

Sessile: An organism that cannot move on its own, usually permanently attached to something.

Shoreface: The sloping zone between a horizontal offshore bottom and low tide.

Silica: The compound SiO_2, the building block of the common mineral quartz.

Silurian: The third geologic period of the Paleozoic Era, following the Ordovician; approximately 443 to 419 Ma.

Siphuncle: The internal passage between chambers in a cephalopod shell.

Skolithos (frequently misspelled *Scolithus*)**:** Cylindrical vertical invertebrate burrows.

Spicule: A structural element of many types of organisms. Many sponges have a skeleton of spicules; the spicules can be simple and toothpick-like or have multiple points, and the form of the tips also varies.

Spikemoss: A member of the order Selaginellales, a group of diminutive plants that reproduce using spores, known from the Pennsylvanian to the present.

Steinkern: A cast of the interior of a hollow organic structure, such as a snail shell, formed when sediments entered the structure and became rock, followed by dissolution of the outer structure.

Stratigraphy: The study of the order and position of rock layers and their place in geologic time.

Stromatolite: A layered microbial mat, typically with a columnar or domal structure.

Stromatoporoid: A member of the class Stromatoporoidea, a group of coral-like reef-building sponges. Stromatoporoids were abundant from the Ordovician into the Devonian. They are regarded as extinct, although some modern sponges are similar.

Strophomenid: A member of the order Strophomenida, an extinct group of articulate brachiopods with wide D-shaped shells, known from the Ordovician into the Pennsylvanian. They lacked pedicles and lived directly on the sea floor.

Stylophoran: A member of the class Stylophora, an extinct group of enigmatic echinoderms featuring broad or ovoid bodies with a single appendage, known from the Cambrian into the Pennsylvanian. Stylophorans are also sometimes known as carpoids.

Subaerial: Exposure of land surfaces under open air.

Subtidal: Zone of the sea floor that remains submerged, lying below low tide level.

Syntype: One of a group of specimens designated as a name-bearing series for an organism.

Tabulate coral: A member of the class Tabulata, an extinct group of colonial corals, known from the Ordovician to the end of the Permian.

Talus: Broken rock shed from cliffs through rock falls; also known as scree.

Taxonomy: The study of naming, defining, and classifying organisms into groups. Taxonomic groups or taxa (singular: taxon) are provided a taxonomic ranking (the main ranks utilized are domain, kingdom, phylum/division, class, order, family, genus, and species, although additional ranks exist).

Tectonics: The processes that produce the structure and properties of the Earth's crust as a result of movements and interactions of tectonic plates.

Test: The formal name for the shells of foraminifera, echinoids, and some other marine organisms.

Time-transgressive: The age of a formation varies from place to place because deposition began earlier in some areas than others, due to factors such as sediment input, sea level, and the depositional environment.

Tippecanoe sequence: The second major sea-level cycle of the Phanerozoic, occurring from the Middle Ordovician to the Early Devonian.

Transcontinental Arch: A now-eroded highland oriented northeast to southwest from Minnesota into the Great Plains that significantly influenced tectonics and sediment dispersal during the deposition of EFMO's rocks.

Tremadocian: A chronostratigraphic stage during the Early Ordovician, approximately 485 to 478 Ma; also known as the Gasconadian stage in North America.

Trilobite: A member of the class Trilobita, an extinct group of marine arthropods known from the Cambrian to the end of the Permian. A typical trilobite had a roughly oval body featuring an axial lobe and two lateral lobes (the three lobes of the name), also divided into three sections (**cephalon** for the head, **thorax**, and **pygidium** for the tail); trilobites vaguely resembled woodlice (roly-poly bugs or pillbugs).

Unconformity: A general term for any erosional or non-depositional surface between two rock units, representing a time gap in the rock record.

USGS: United States Geological Survey.

Valve: A shell. Snails and monoplacophorans are univalved (one shell) and bivalves and brachiopods are bivalved (two shells).

Western Interior Seaway: A shallow continental sea that covered much of the midsection of North America from the Arctic to the Gulf of Mexico between approximately 100 and 70 Ma, during the Cretaceous. Lowering sea levels and the growth of the Rocky Mountains caused it to recede.

Acknowledgments

Every project we do requires cooperation, support, and assistance from many people, both within and outside of the NPS. The administration and staff of Effigy Mounds National Monument (EFMO) have been extraordinarily welcoming, enthusiastic, and supportive of this project, which is especially notable for a topic that at first glance seems far removed from the monument's primary resource concerns. They could have easily said "no" at the outset or left me (Justin) to puzzle out the roads leading to the Heritage Addition, but instead they have supported the project every step of the way. We recognize the able assistance and contributions of current and former EFMO staff, including superintendent Susan Snow, Katherine Busse, Alex Coté, Albert LeBeau, Fred MacVaugh, Jeanette Muller, Carrie Nelson, Sheila Oberreuter, René O'Donnell-Hanlon, and Jeremy Parker. They have gone above and beyond the call of duty to make this project a success. Furthermore, at every turn, it seemed that something new and interesting emerged as a result of this collaboration, from the fossil-producing localities themselves, to the unexpected discovery of a fossil report from the mid-19th century, to the remarkable Orr collection and Orr's correspondence with Frederick Sardeson, a figure familiar from my own interest in Minnesota paleontology.

We also had key assistance from various people and institutions outside the monument. Tiffany Adrain (University of Iowa), Caroline Parris (Iowa Office of the State Archaeologist), and Laura Peterson (Luther College) provided information regarding specimens under their care and the Ellison Orr collection. Thomas Parr (Great Lakes Inventory & Monitoring Network program manager) served as peer review coordinator. Finally, Robert B. Blodgett (consulting paleontologist/geologist) and Ryan Clark and Jack Malone (Iowa Geological Survey) provided invaluable reviews.

Introduction

Effigy Mounds National Monument (EFMO), located on the west side of the Mississippi River in northeastern Iowa, was proclaimed on October 25, 1949. It preserves a significant concentration of prehistoric burial mounds constructed between 450 BCE and 1300 CE, including outstanding examples of the namesake effigy mounds created in the shapes of bears and birds. Its boundaries changed May 27, 1961, October 31, 1983, and October 19, 2000, and today it encompasses 1,022.39 hectares (2,526.39 acres) of federal lands. EFMO is divided into four administrative units (Figure 1). Three of the units are geographically contiguous and are mostly located in Allamakee County, with a small area within northern Clayton County: the North Unit, which includes the Great and Little Bear Mound Groups, Eagle Rock, Fire Point, Hanging Rock, and the monument's administrative buildings; the South Unit, which includes the Compound Mound Group and Marching Bear Group, Founders Pond, and Nezekaw Point; and the undeveloped Heritage Addition, added to the monument in 2000. The Yellow River passes through the Heritage Addition and separates the North and South Units. These three units are just north of Marquette, Iowa, a little less than 5 km (3 mi) north of McGregor, Iowa and Pikes Peak State Park, and across the Mississippi River from Prairie du Chien, Wisconsin. Together these units of EFMO host a complex landscape of rivers, ponds, steep bluffs, ravines, gullies, floodplains, forests, and prairie. There is also a small detached unit, the Sny Magill Unit, located in the Mississippi River floodplain at the mouth of Sny Magill Creek about 13 km (8 mi) south of the rest of EFMO, about 16 km (10 mi) north of Guttenberg, Iowa. EFMO and its surroundings in northeastern Iowa are within the heavily eroded physiographic landscape of the Paleozoic Plateau (Prior 1991). This is also sometimes described as the Driftless Area, in reference to the apparent absence of glacial deposits, but as discussed later in this report, this area of Iowa actually does have some glacial deposits, so some authorities prefer the other name for accuracy (e.g., Hallberg et al. 1984; Tassier-Surine 2000). The land on the other side of the Mississippi, though, is genuinely driftless.

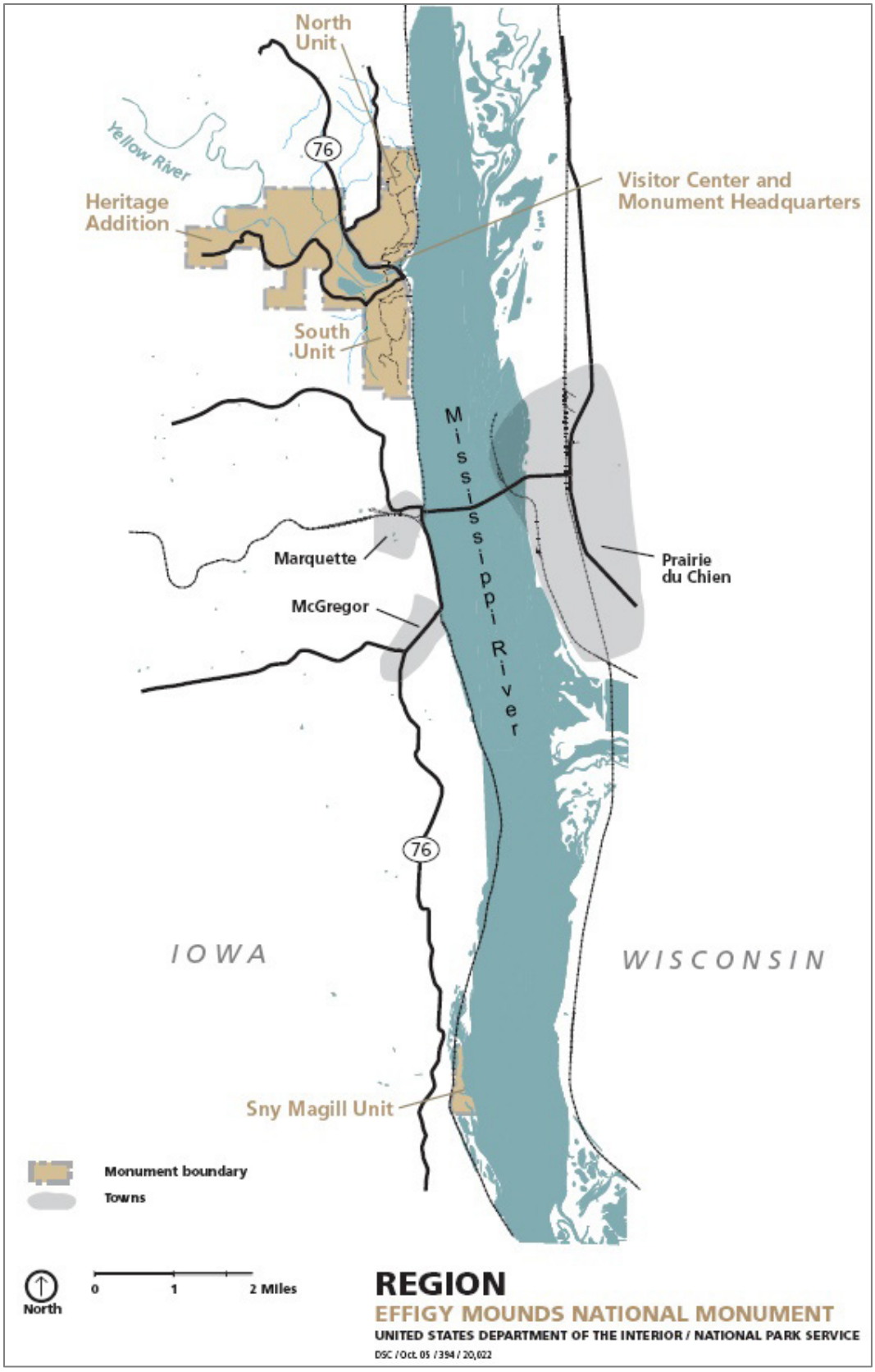


Figure 1. Park map of EFMO. NPS; Mississippi River annotation added.

Geological and paleontological research has occurred in this area of northeastern Iowa and adjoining Wisconsin since the middle of the 19th century (e.g., Owen 1852), and several of the rock units that are visible in EFMO or are mapped there were named for locations in the region: the Prairie du Chien Group, named for Prairie du Chien (Bain 1906); the Oneota Formation, named for the Oneota River (now known as the Upper Iowa River) (McGee 1891); the Glenwood Formation, named for Glenwood Township, about 40 km (25 mi) northwest of EFMO (Calvin 1906); the McGregor Member of the Platteville Formation, named for McGregor (Kay 1935); the Decorah Formation, named for Decorah, Iowa, about 53 km (33 mi) northwest of EFMO (Calvin 1906); the Spechts Ferry Member of the Decorah Formation, named for Spechts Ferry, Iowa, about 48 km (30 mi) southeast of the Sny Magill Unit (Kay 1928); the Guttenberg Member of the Decorah Formation, named for Guttenberg (Kay 1928); and the Ion Member of the Decorah Formation, named for Ion, Iowa, less than 5 km (3 mi) northwest of EFMO (Kay 1928). Despite this regional geological and paleontological pedigree, the paleontology of EFMO had not been a topic of study until the present inventory, which collects existing knowledge and documents previously unrecognized fossil resources of Late Ordovician age present in several areas of the monument.

This report provides detailed information on the paleontological resources of EFMO, including the history of paleontological work in the lands now within the monument, geologic units, taxonomic groups, localities, museum collections, research, interpretation, and management and protection. In addition to the main body of text, there are four appendices: Appendix A, lists of paleontological species arranged by stratigraphy; Appendix B, contact information for repositories; Appendix C, paleontological resource law and policy; and Appendix D, a geologic time scale.

Significance of Paleontological Resources at EFMO

The paleontological resources at EFMO add detail to the monument's natural history and provide a fuller picture of its context. They are part of the natural fabric of the monument and help to explain its landscapes and topography. The fossils place EFMO in a regional geological and paleontological framework and provide a point of comparison to Mississippi National River and Recreation Area and Saint Croix National Scenic Riverway, two other NPS units in the region with similar geology and fossils. The paleontological resources of EFMO were previously almost entirely unknown, but their scope and extent have now been documented—an essential step for the effective management of these non-renewable resources. The distribution of the greatest concentrations of fossils is also predictable, which is useful for planning, e.g., for infrastructure work or trail placement (particularly in the Heritage Addition), or if any tracts are added to the monument, such as those indicated in the EFMO General Management Plan (NPS 2013). Understanding EFMO's paleontological resources addresses items that the monument considers important for management: the General Management Plan considers the monument's bedrock as an important resource under Significance Statement 2, and Ellison Orr's collection (including fossils) as a fundamental resource under Significance Statement 4. Analysis of EFMO's paleontological resources from the recent past allows a better understanding of the ecosystem when people were building the mounds, illustrating potential human interactions with the local environment and providing information that can be used for reconstructions of the setting. These resources also represent a warm period during the Holocene and therefore provide some idea of how the local ecosystem may respond to warmer climate in the near

future. Paleontological resources at EFMO are also known to be connected to some cultural resources (e.g., fossil shells in chert found at a site identified as a Native American chert quarry) and may have additional links yet to be discovered.

Purpose and Need

The NPS is required to manage its lands and resources in accordance with federal laws, regulations, management policies, guidelines, and scientific principles. Those authorities and guidance directly applicable to paleontological resources are cited below in Appendix C. Paleontological resource inventories have been developed by the NPS in order to compile information regarding the scope, significance, distribution, and management issues associated with fossil resources present within parks. This information is intended to increase awareness of park fossils and paleontological issues in order to inform management decisions and actions that comply with these laws, directives, and policies. Options for paleontological resource management are locality-specific and may include: no action; surveys; site monitoring; cyclic prospecting or other fossil collecting undertaken with an approved permit; stabilization and reburial; shelter construction; excavation; closure; patrols; and alarm systems or electronic surveillance. See Appendix C for additional information on applicable laws and legislation.

Project Objectives

This park-focused paleontological resource inventory project was initiated to provide information to EFMO staff for use in formulating management activities and procedures that would enable compliance with related laws, regulations, policies, and management guidelines. Additionally, this project will facilitate future research, proper curation of specimens, and resource management practices associated with the paleontological resources at EFMO. Methods and tasks addressed in this inventory report include:

- Locating, identifying, and documenting paleontological resource localities through field reconnaissance and perusal of archives, using photography, GPS data, and other sources.
- Identifying and assessing historical fossil localities.
- Assessing collections of EFMO fossils maintained within monument collections and in outside repositories.
- Generating taxonomic lists and providing paleoecological reconstructions.
- Interviewing staff to gather information on the current status of paleontological resources, to aid in formulating plans for management, resource protection, ideas for interpretation, and recommendations.
- Conducting a thorough search for relevant publications, unpublished geologic notes, and outside fossil collections from EFMO.

History of Paleontological Work at EFMO

Paleontology, or any other geoscience, has historically not been a focus of interest at EFMO, although the role of geology in forming the striking river valley landscapes has been recognized, and chert-rich outcrops are known to have been exploited for tool material. It is therefore interesting to note that there is a report of paleontological resources from the future location of EFMO made during the middle of the 19th century. One of the early major geological surveys of the region, conducted by David Dale Owen during the late 1840s, visited the area of Prairie du Chien and the mouth of the Yellow River (Owen 1852; Shumard 1852). Benjamin Franklin Shumard led the party that surveyed in the EFMO area in 1848. Shumard briefly described the geology at the mouth of the river and made the first report of fossils from the monument (Shumard 1852: 504):

> *Similar bluffs extend to the mouth of Yellow River, the junction between F.1* [Jordan Formation in this context] *and 2* [Prairie du Chien Group in this context] *declining gradually about one hundred feet in a distance of about three miles* [from near Paint Rock]. *At this place the magnesian limestone* [Prairie du Chien Group] *is traversed, near its summit, by seams of chert, and contains* Euomphalus *and another Gasteropod, which appears to be a species of* Natica.

Today, the bluffs at the mouth of the Yellow River are within EFMO for approximately 2.3–2.4 km (1.4–1.5 mi) on either side, so it is almost certain that Shumard visited what is now the monument and documented fossils there. In taxonomic terms, both of the names he invoked would no longer be applied to Ordovician fossils; "*Euomphalus*" suggests a shell with a flat or low coil and "*Natica*" suggests a shell with a steeper coil and more triangular profile.

Although fossils have been formally reported on occasion from the area around EFMO for many years (e.g., Calvin 1892; Thomas 1926; Furnish 1938; Edwards 1988), the next report from EFMO itself was not until McKay (1993), more than 140 years later. It is worth noting, though, that Ellison Orr, a key founding figure of EFMO, evidently had a strong interest in paleontology along with his wider interest in natural history, as evidenced by the thousands of fossil specimens he collected from northeastern Iowa and elsewhere (see "Museum Collections and Curation" below).

McKay (1993), like the previous report by Shumard, documents fossils in passing. In this case, they are part of a stratigraphic section taken at Hanging Rock, from the level of the river to the top of the bluff. Stromatolites and invertebrate burrows are reported in the Jordan Formation and overlying Oneota Formation, but not described in detail (McKay 1993). More recently, McGuire Bogen and Hotchkiss (2007) described various paleontological resources found in a core taken from Founders Pond, dating through almost the entirety of the Holocene. These materials included spores, pollen, seeds, peat, gastropod shells, diatoms, and algae. Together, Shumard (1852), McKay (1993), and McGuire Bogen and Hotchkiss (2007) appear to be the only non-summary publications reporting fossils from EFMO. Hunt et al. (2008), a paleontological resource summary for the Heartland Inventory & Monitoring Network, summarized information on EFMO paleontology, and Graham (2011), a geologic resource scoping summary, included a small number of additional details.

Summary of 2023–2024 Paleontological Work at EFMO

The lead author had long been interested in conducting a paleontological inventory at EFMO, because of his familiarity with the geologic formations mapped there, his previous work at EFMO's geological "siblings" Mississippi National River and Recreation Area (MISS) (Tweet 2014) and Saint Croix National Scenic Riverway (SACN) (Tweet and Santucci 2018), and the report of a large number of fossils in EFMO collections (Hunt et al. 2008). In spring 2023, after discussion with EFMO management, a technical assistance request (TAR# 29926) was submitted seeking a paleontological resource inventory for EFMO, and Tweet began making plans for field work.

An initial visit was made July 7, 2023, to reconnoiter the monument for planning and meet the staff. Tweet met Superintendent Susan Snow, Cultural Resources Manager Albert LeBeau, Interpretation & Education Program Manager Fred MacVaugh, and seasonal Biological Technician Katherine Busse, who led him to several fossiliferous areas. A second longer visit was planned for the autumn, when vegetation would be reduced. After a delay precipitated by anticipated bad weather, Tweet made the second visit November 13–15, inspecting the North and South Units, the Heritage Addition, and the monument's paleontological collections. These visits established that there are typical Platteville Formation fossils in the monument. Also of note, an area identified as a Native American chert quarry includes fossiliferous chert. Field work was conducted under permit EFMO-2023-SCI-0002. No fossils were collected during this inventory.

Geology

Geologic History

The geologic history of EFMO and its surroundings, as expressed in the rocks visible at the surface, is dominated by shallow marine deposition during the early and middle Paleozoic. This time frame spans from shortly before 500 Ma (million years ago) to about 380 Ma. The rocks visible at EFMO take up a fraction of that range, from around 495 to 450 Ma in the early Paleozoic.[1] At this time Laurentia, the North American craton, was situated much differently compared to the present: It was rotated close to 90° clockwise and straddled the equator, with the Upper Midwest in the Southern Hemisphere. "North" would have then been east to east–northeast (most publications retain modern directions for convenience; this convention will be followed here) (Figure 2) (Mossler 2008; Ojakangas 2009).

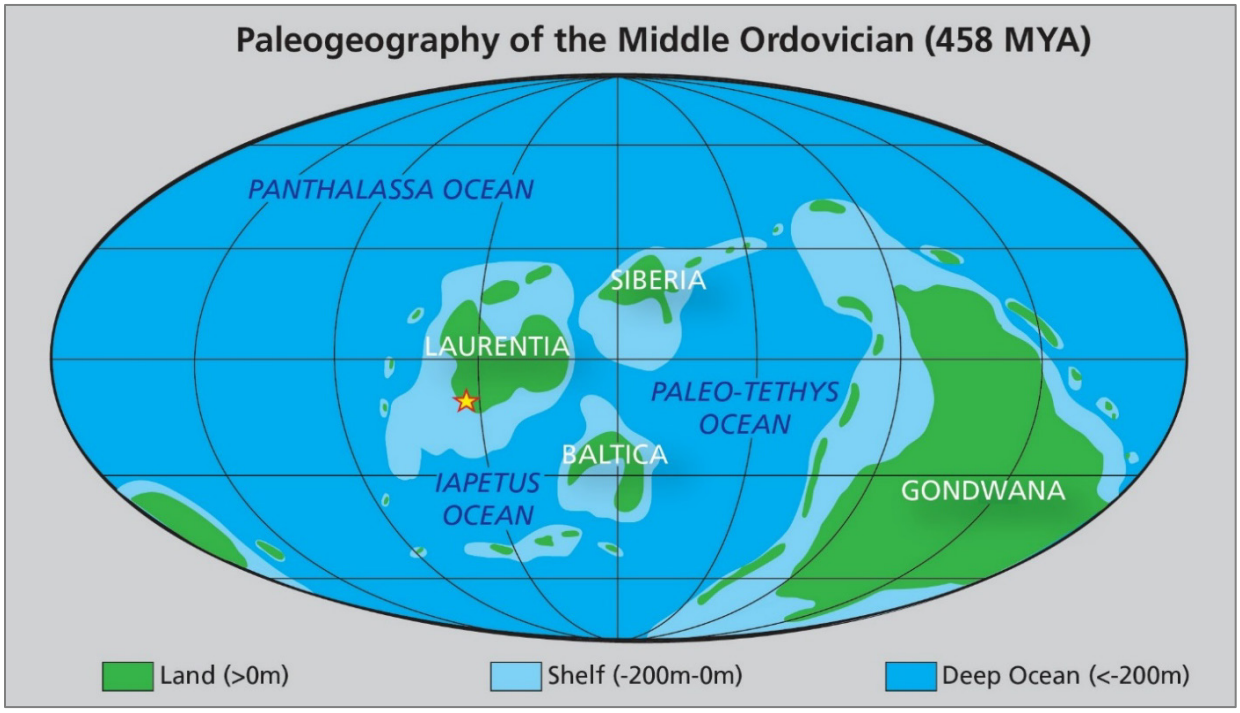


Figure 2. A simplified paleogeographic reconstruction of the late Middle Ordovician, approximately the time of the deposition of the St. Peter Sandstone. Laurentia is the ancient core of North America. A star has been added to approximate the location of EFMO. Base figure from Lanik et al. (2019: Fig. 42). NPS

The lower Paleozoic rocks in northeastern Iowa were deposited into a basin between topographic highs on the north, west, and east (Mossler 2008). The upper Cambrian formations were all deposited

[1] Note that in geological terminology, positional terms ("lower", "upper") are used when describing rock units as physical things, whereas chronological terms ("early", "late") are used when describing the age of a unit. These terms are capitalized if formal, lowercase if not, e.g., the divisions of the Ordovician are formal, but the late or upper Cambrian is informal.

within a fairly short interval, approximately 500 to 490 Ma. The more recent Ordovician rocks are more separated in time; the Oneota and Shakopee Formations were deposited between approximately 486 and 480 Ma with a brief hiatus between them (Smith and Clark 1996), and the St. Peter Sandstone–Dunleith Formation sequence dates to approximately 460 to 450 Ma (Mossler 2008). Broadly speaking, the rocks record parts of two major marine transgression–regression sequences. The first, known as the Sauk sequence, occurred from the Cambrian into the Early Ordovician; the second, the Tippecanoe sequence, occurred from the Middle Ordovician into the Early Devonian (Sloss 1963). Smaller sea level cycles occurred within the Sauk and Tippecanoe sequences. For example, the Oneota and Shakopee Formations represent two major sub-cycles of the Sauk sequence, and the two formations each have two members that represent yet smaller cycles of sea level change (Smith et al. 1996).

Eventually, a wide area was submerged under marine waters. The Sauk continental sea was shallow and warm (Hughes 1991), and a variety of life lived in and at the seafloor and within the water column. However, the fauna was unusual compared to what had come before and what would come soon after. The Cambrian rocks of the EFMO area were deposited during an unusual phase sometimes called the “Dead Interval” or the “Late Cambrian Plateau”, an episode of 25 million years between the Cambrian Explosion and diversification later in the Ordovician. Widespread extinction events removed many Cambrian groups, leaving a low-diversity fauna characterized by brachiopods, trilobites, and conodonts. These surviving groups underwent rapid turnover (Runkel et al. 2010). The driving forces behind this unstable period are controversial; widespread cyclic cold climate conditions (Runkel et al. 2010), strong transgression–regression cycles with low oxygen (Landing 2011), and periodic expansion of oxygen-depleted deep ocean waters into shallow marine areas (Gill et al. 2011) have been suggested. Burrows from unknown animals, perhaps soft-bodied worm-like invertebrates, are also abundant. Following the productive but low-diversity upper Cambrian rocks and the sparsely fossiliferous Lower Ordovician rocks, the Upper Ordovician rocks of the region contain abundant and diverse fossils. These fossils are primarily of immobile seafloor-dwelling filter feeders and predators of microscopic prey, such as solitary and colonial corals, bryozoans, brachiopods, bivalves, and crinoids, with snails and trilobites moving among them and squid-like nautiloids as the top predators (Tweet 2014).

The Upper Midwest is not generally thought of as a location for dramatic geological events, but one such event took place during the Middle Ordovician near Decorah. Buried beneath the city is a crater approximately 5.6 km (3.5 mi) across (French et al. 2018) from a meteorite impact that took place between 467 and 464 Ma, potentially as part of a larger swarm of craters known from this time frame (Bergström et al. 2018). A unique geological formation preserving unusual fossils, the Winneshiek Shale, was deposited in this crater basin (Bergström et al. 2018). This event took place between the deposition of the Shakopee Formation of the Prairie du Chien Group and the younger St. Peter Sandstone. The Prairie du Chien Group rocks of EFMO include significantly brecciated intervals (Figure 3), and it is tempting to associate the crater with these because of its proximity, although it is odd that disruption would be confined to certain beds (unless those beds were more susceptible). Instead, the disrupted or brecciated beds of the Prairie du Chien Group represent paleo-karst

formation caused by the subaerial exposure of carbonate rocks during the marine regression at the end of the Sauk sequence (Smith et al. 1996).



Figure 3. Thoroughly brecciated beds in the Prairie du Chien Group, Heritage Addition. The scale bar used here and in other figures has 1 cm (0.4 in) black and white squares and millimeter-scale (0.04 in) tick marks, which are not visible here. NPS / JUSTIN TWEET

Deposition continued in the region through more of the Late Ordovician and into the succeeding Silurian and Devonian. Younger Silurian and Devonian rocks are mapped in the area of the Yellow River drainage basin, but any younger rocks that may have been deposited have not been preserved, with the exception of an isolated area north of Waukon attributed to the mid-Cretaceous Windrow Formation (Witzke and Anderson 2006). The Windrow Formation is a remnant of coastal plain and shallow marine deposition that occurred on the eastern shore of the Western Interior Seaway, a shallow Cretaceous continental sea that existed during a time of very high sea level before the growth of the Rocky Mountains (Sloan 1964; Cobban and Merewether 1983). With the youngest Devonian rocks described as Middle Devonian (between approximately 394 and 379 Ma), and the middle of the

Cretaceous at approximately 100 Ma, the sequence of events is approximately 280 million years of erosion and non-deposition, then a brief interval of preserved deposition followed by another approximately 100 million years of erosion and non-deposition until the present. For various geological reasons, the Upper Midwest has not been a significant depositional basin since the middle Paleozoic, and without a rock record little is known of the events that occurred except as can be extrapolated from surrounding areas.

The geologic record does not resume in this area until nearly the present. Although the deeply dissected topography of northeastern Iowa, southeastern Minnesota, southwestern Wisconsin, and northwestern Illinois is frequently described as the "Driftless Area", only part of this area is known to have escaped glaciation entirely (Hallberg et al. 1984; Knox 2019). EFMO is within an area that had pre-Illinoian glaciation (before 300,000 years ago) (Knox 2019). In addition, it should be recognized that although this area has not been directly affected by glaciation for hundreds of thousands of years, it has been heavily affected by the nearby presence of glaciers. The drainage network of the area reflects the most recent glacial episode, with major downcutting, aggradation, and terrace building dating to that time (Hallberg et al. 1984). Some locations within EFMO, far above the modern drainage network, show evidence of an earlier higher stage of flowing water (Figure 4). With the most recent glacial retreat, silt was blown in, forming loess deposits; these date to about 16,000 to 14,000 years ago (Knox 2019).



Figure 4. An undercut outcrop of the Prairie du Chien Group in the Heritage Addition. It is far above the modern drainage but shows significant undercutting, indicating that water once flowed through in greater quantities than could be delivered by the small ravine to the left. NPS / JUSTIN TWEET

This report focuses on the combined North and South Units and Heritage Addition, as the Sny Magill Unit is located in the Mississippi River floodplain and lacks outcrops. This does not preclude the possibility of the Sny Magill Unit having either detrital fossils transported by rivers, or Quaternary paleoecological resources that can be found by taking cores (Graham 2011 notes the presence of gravel sourced from as far away as the Lake Superior area, so there is certainly not an issue of range). For reference, the former would generally be similar to fossils known from the northern EFMO holdings because the same formations would be eroding into the drainage in the vicinity, and the latter would be comparable to the Founders Pond record described under "Quaternary Rocks and Sediments" below. The stratigraphic formations of the northern holdings include, in ascending order (from oldest to youngest), the Jordan Formation (upper Cambrian), Oneota and Shakopee Formations of the Prairie du Chien Group (Lower Ordovician), St. Peter Sandstone (Middle–Upper Ordovician), and the Upper Ordovician Glenwood, Platteville, Decorah, and Dunleith Formations (Figures 5 and 6) (Witzke and Anderson 2006). The Sny Magill Unit is mapped over undivided buried rocks of the Prairie du Chien Group and St. Peter Sandstone (Figure 7) (Witzke et al. 2010). See Table 1 for a summary of EFMO's geology. Good outcrops of the Jordan Formation, Prairie du Chien Group, and St. Peter Sandstone can be seen in EFMO, and localized outcrops of the Platteville Formation can be seen in the far western Heritage Addition. The presence of the other units is inferred from stratigraphy (e.g., the thin and non-resistant Glenwood Formation is located between the outcropping St. Peter Sandstone and Platteville Formation) or geologic mapping (the Decorah and Dunleith Formations), but potential outcrops are covered by surficial deposits.

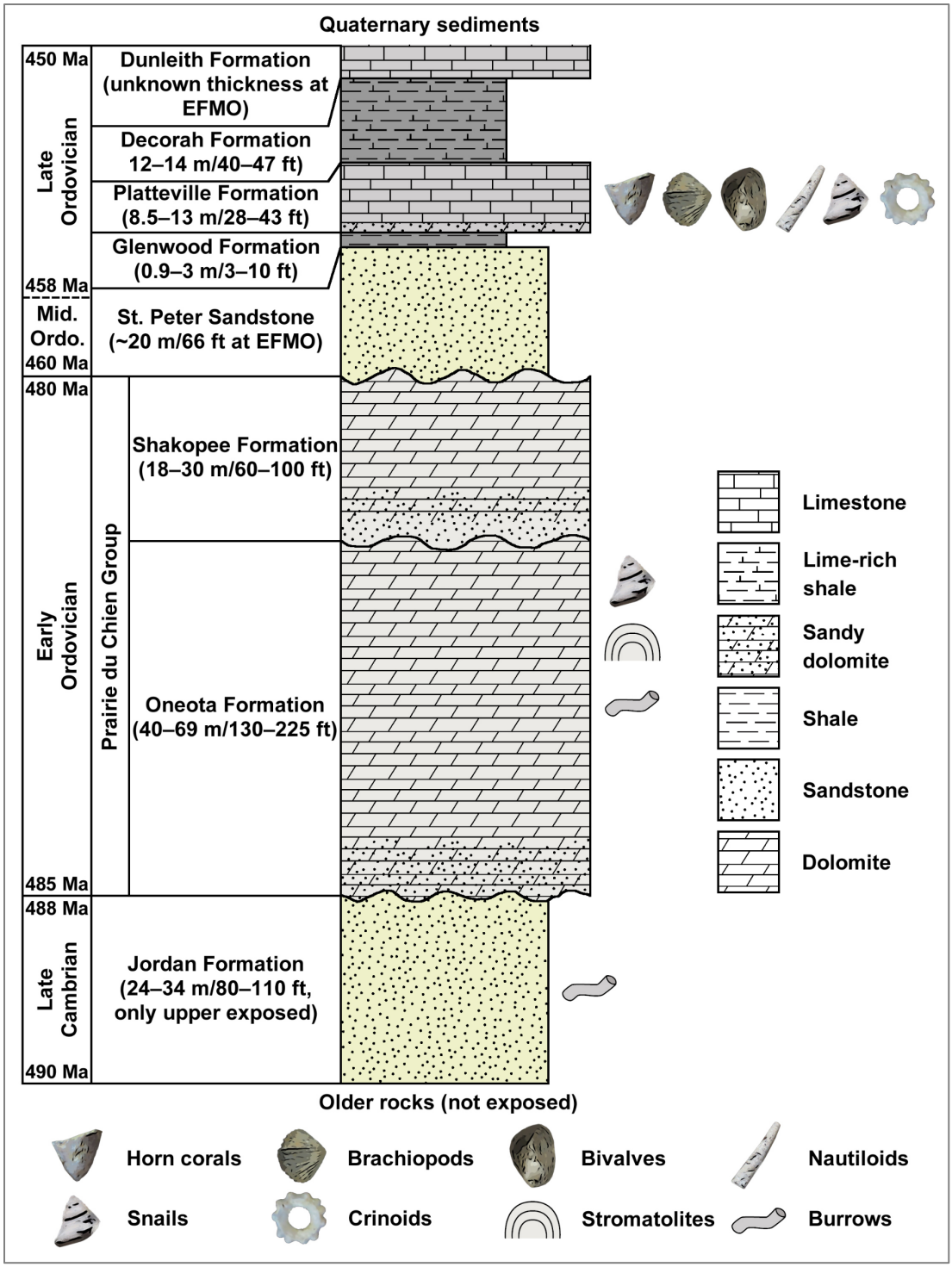


Figure 5. Schematic stratigraphic column of EFMO bedrock formations, with common fossils seen in the monument. Thicknesses and lithologies after Witzke and Anderson (2006) and personal observations, ages per sources in this report. Dates are for the approximate ages of the rocks, not the geologic periods. Unconformities (wavy contacts between some formations) are exaggerated. Fossils of the undifferentiated Prairie du Chien Group are represented halfway up the unit. Lithologic patterns and symbols for burrows and stromatolites are taken from the Federal Geographic Data Committee's standards (https://pubs.usgs.gov/tm/2006/11A02/). NPS / JUSTIN TWEET

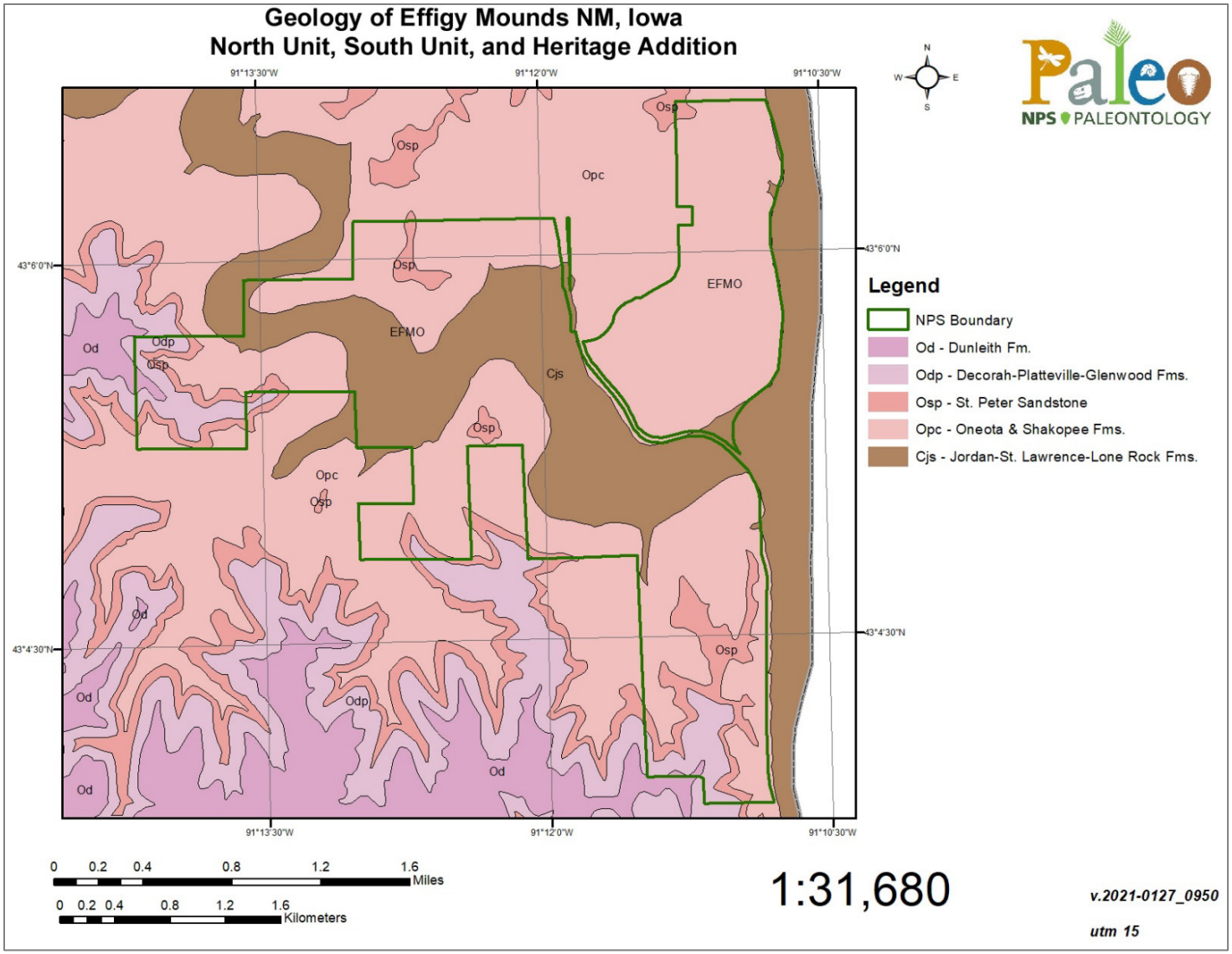


Figure 6. Geologic map of EFMO (North and South Units and Heritage Addition), Iowa. Data modified from EFMO GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2175686.

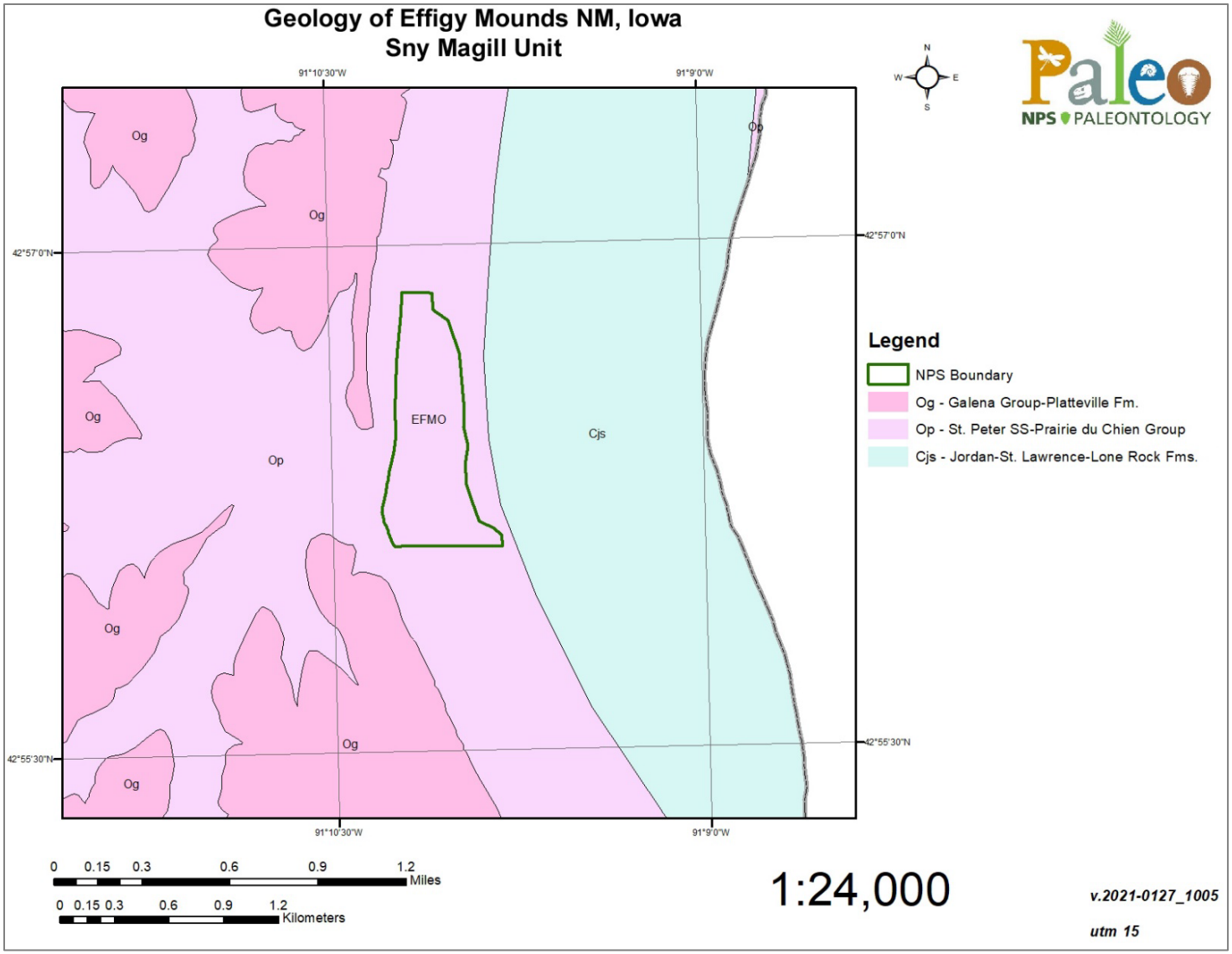


Figure 7. Geologic map of EFMO (Sny Magill Unit), Iowa. Data modified from EFMO GRI digital geologic map data at https://irma.nps.gov/DataStore/Reference/Profile/2175688.

Table 1. Summary of EFMO stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text and in Hunt et al. (2008).

Formation	Age	Fossils Within EFMO	Depositional Environment
Quaternary sediments	Pleistocene–Holocene	Holocene spores (lycopods and others), pollen (conifers and angiosperms), seeds, woody fragments, charcoal, peat, gastropods, unspecified shells, diatoms, and unspecified algae	Fluvial, lacustrine, colluvial, alluvial
Galena Group: Dunleith Formation	Late Ordovician	None to date	Shallow marine
Galena Group: Decorah Formation	Late Ordovician	None to date	Shallow marine
Platteville Formation	Late Ordovician	Horn corals, bryozoans, brachiopods, hyoliths, bivalves, nautiloids, gastropods, trilobites, ostracodes, crinoids, and invertebrate burrows/trails	Shallow marine
Glenwood Formation	Late Ordovician	None to date	Shallow marine
St. Peter Sandstone	Middle–Late Ordovician	None to date	Coastal and shallow marine
Prairie du Chien Group: Oneota Formation and overlying Shakopee Formation	Early Ordovician	Gastropods, unidentified shells, a ringed fossil, stromatolites, and invertebrate burrows/trails	Shallow marine
Jordan Formation	Late Cambrian	Invertebrate burrows/trails and bioturbation, and possible stromatolites	Coastal and shallow marine

Geologic Formations

Jordan Formation (Upper Cambrian)

Description: In the Yellow River drainage basin, the Jordan Formation (sometimes called the Jordan Sandstone) is composed largely of very-fine to medium-grained sandstone, with coarser beds in the upper part, and some minor sandy dolostone and dolomitic cement. Some strata are prominently cross-bedded. The formation is 24–34 m (80–110 ft) thick (Witzke and Anderson 2006). At EFMO, the Jordan Formation is prominently exposed in the lower part of the bluff adjacent to Iowa Highway 76 in the South Unit. (It should be noted that the portion of the bluff immediately adjacent to the road is technically just outside of EFMO, but the monument and non-monument parts are contiguous.) The bluff exposures continue north of the Yellow River, adjacent to the railroad, but these outcrops are much less visible to visitors. The formation can be inspected at close range around the South Unit trailhead, but this should only be done with caution because of the highway. The exposures weather to a light brownish-yellow to gray color except on fresh surfaces, which appear nearly white. The weathering profile is notably irregular, with ledges several cm or inches thick standing out. Planar lamination and cross-bedding are visible on some beds (Figure 8). The contact with the overlying Oneota Formation is mapped close to 200 m (656 ft) in the immediate area of EFMO (Witzke and Anderson 2006).



Figure 8. An outcrop of Jordan Formation near the South Unit trailhead. It includes distinct resistant beds and cross-bedding (some of which resembles herringbone cross-stratification, usually interpreted as tidal deposition). NPS / JUSTIN TWEET

In older reports, descriptions of the Jordan Formation in the EFMO area vary depending on the assignment of a stratigraphic interval known as the Coon Valley Member. McKay (1993) on the section at Hanging Rock included it in the Jordan Formation, but it is now usually placed at the base of the overlying Oneota Formation of the Prairie du Chien Group (e.g., McKay 2000; Witzke 2000; Witzke and Anderson 2006).

Overall, the Jordan Formation is made up of two sandstone facies, one composed of fine- to coarse-grained quartz-rich sandstone and the other composed of very-fine-grained feldspar-rich sandstone (Mossler 2008). These two facies roughly correspond to what had been identified as the Van Oser and underlying Norwalk Members, but these member names have been dropped because the facies are made up of a number of distinct "tongues" of rock, so that they cannot be mapped or described as large-scale discrete geologic units (Runkel 1994a; Mossler 2008). The upper contact with the Oneota Formation is disconformable, marked by a sharp undulatory contact and a pebble lag at the base of the overlying Oneota Formation (Runkel 1994b; Mossler 2008). The Jordan Formation is a shallow marine sandstone, deposited under tens of meters of water at most, between the coast and areas of carbonate deposition farther offshore (Byers and Dott 1995). It was deposited during a marine regression, with rocks representing progressively shallower and more nearshore deposition over time (Runkel 1994b; Byers and Dott 1995; Tape et al. 2003). Deposition shifted from lower shoreface and offshore shelf areas near the base of the formation to upper shoreface at the top of the formation, and the sediment became coarser (Runkel 1994b). The uppermost part of the formation shows sedimentary structures typical of tides (Runkel 1994a; Byers and Dott 1995; Tape et al. 2003). Fossils indicate the formation dates to the late Cambrian (Runkel et al. 2007; Mossler 2008).

Fossils found within EFMO: McKay (1993) reported trace fossils in the "Van Oser Member" at the Hanging Rock section, including the simple vertical invertebrate burrow *Skolithos*, unspecified burrows and bioturbation, and possible stromatolites. In another area of EFMO Tweet observed a bioturbated fallen block (Figure 9). (See "Taxonomy" below for a discussion of fossil groups.)



Figure 9. A heavily burrowed shed block of the Jordan Formation. NPS / JUSTIN TWEET

Fossils found elsewhere: The Jordan Formation is sparsely fossiliferous. Stauffer and Thiel (1941) provided faunal lists for the Van Oser and Norwalk Members of the Jordan Formation in Minnesota, including brachiopods, hyoliths, gastropods, helcionelloids, trilobites, aglaspidids, and invertebrate trace fossils. More recent work also includes conodonts (e.g., Runkel et al. 2007). Body fossils are rare, but burrows are common (Mossler 2008); body fossils tend to be more common in the lower part of the formation (Nelson 1949). McKay (2000), describing the Jordan Formation in and around Pikes Peak State Park, reported the presence of conodonts and *Skolithos* burrows.

Prairie du Chien Group (Lower Ordovician)

Description: The Prairie du Chien Group is a resistant unit that forms the bluffs facing the Mississippi River in EFMO. It is composed primarily of dolostone, with some quartz sandstone, sandy dolostone, and chert nodules and masses (Witzke and Anderson 2006); chert-rich intervals are known to have been quarried by Native Americans in this region to make tools and projectile points. The Prairie du Chien Group in the Yellow River Basin includes two formations that are mapped together, in ascending order the Oneota Formation (sometimes called the Oneota Dolomite) and overlying Shakopee Formation (Witzke and Anderson 2006). The two formations have an unconformable contact (Mossler 2008). Both formations are divided into two members. The Oneota Formation includes the Coon Valley Member (formerly included as the upper member of the underlying Jordan Formation; e.g., McKay 1993) and the overlying Hager City Member. The Coon Valley Member is composed of sandy dolostone with thin sandstone and minor chert, and the Hager City Member is composed of dolostone and cherty dolostone (Witzke and Anderson 2006). The Shakopee Formation includes the New Richmond Member and overlying Willow River Member. The New Richmond Member is a heterogeneous unit of sandstone, sandy dolostone, and minor chert, whereas the Willow River Member is composed of dolostone (some sandy or cherty) and minor green shale (Witzke and Anderson 2006). The group as a whole is typically 73–102 m (240–335 ft)

thick in the area, thicker to the south, but can be significantly thinner (Witzke and Anderson 2006). This is a function of erosion before the deposition of the overlying St. Peter Sandstone (Witzke 2000). Within EFMO, the map by Witzke and Anderson (2006) suggests that the contact with the St. Peter Sandstone is generally around 280 m (920 ft) in elevation, plus or minus approximately 6 m (20 ft). With a basal contact about 200 m (656 ft), this would imply a typical thickness of approximately 80 m (260 ft). The Oneota Formation in the Yellow River Basin is generally 40–69 m (130–225 ft) thick, and the Shakopee Formation is generally around 18–30 m (60–100 ft) thick (Witzke and Anderson 2006). Although the group as a whole is generally a ledge- or bluff-forming unit (Figure 10), the upper Shakopee Formation is less resistant and usually forms slopes (Witzke and Anderson 2006). The group may also display karst weathering (Witzke and Anderson 2006), and cave features from rock shelters to small caves can be found in EFMO (pers. obs., 7 July 2023).



Figure 10. A typical bluff-forming outcrop of the Prairie du Chien Group near the South Unit trailhead. The yellowish color is enhanced by early morning sunlight. NPS / JUSTIN TWEET

Within EFMO, the steep exposures of the Prairie du Chien Group make for picturesque landscapes and provide outlooks for expansive views of the Mississippi River Valley, but the same steepness also restricts direct observation to areas where the rocks are adjacent to sufficient footing. Weathering has made many surfaces look monotonous, with a dirty gray color, but close inspection and fresher surfaces show chert nodules, small voids, heavily brecciated intervals, and other features (pers. obs., 7 July and 13/14 November 2023). Rockfalls and slides sometimes occur, as shown by an area on the north face of the thin ridge roughly paralleling the Heritage Addition's border with the Yellow River State Forest to the north (Figure 11); Katherine Busse (EFMO biological technician, pers. comm., 7 July 2023) estimates this event to have occurred around March 2023.



Figure 11. A large rockslide. **A.** The bluff outcrop source. **B.** Large shed blocks have torn out trees. NPS / JUSTIN TWEET

Overall, the Prairie du Chien Group is interpreted as a marine carbonate bank with microbial reefs (Webers 1972a; Smith et al. 1996). Periodic influxes of sand buried and killed the microbial forms. The prevalence of fossil microbial structures, the small size of invertebrate body fossils, and the rarity of bottom-dwelling filter feeders suggest stressful environmental conditions (Webers 1972a). Early in deposition there was occasional subaerial exposure, as evidenced by mudcracks in the Coon Valley Member near Marquette (McKay 1993). The two formations were deposited under successive transgression-regression cycles (Austin 1972; Webers 1972b; Smith et al. 1996), and their individual members reflect smaller-scale cycles (Smith et al. 1996). Deposition ended when sea level dropped during the transition from the Sauk sequence to the Tippecanoe sequence (Smith et al. 1996). Microfossils indicate that the Prairie du Chien Group was deposited during the early and middle portions of the earliest geochronological age of the Ordovician (the Tremadocian, approximately 485 to 478 Ma), with a hiatus between them (Smith and Clark 1996).

Fossils found within EFMO: McKay (1993) reported stromatolites and *Skolithos* burrows in the Coon Valley Member and stromatolites in the overlying Oneota at the Hanging Rock section. Tweet observed shell cross-sections in chert (including one identifiable as a gastropod) (see "Phylum Mollusca: Class Gastropoda (snails)" below), an enigmatic ringed feature (see "Other Invertebrates" below), heavily burrowed blocks of Prairie du Chien rock (see "Ichnofossils" below), and a fallen block that appears to be stromatolitic (Figure 12). Fossils are likely more abundant than known, but access to many outcrops is complicated by their verticality, and many of the fossil types may not be immediately recognizable to viewers.



Figure 12. A shed block. It has the characteristic contorted surface of a stromatolitic bedding plane and probably fell from the overlooking Prairie du Chien Group bluffs. NPS / JUSTIN TWEET

Fossils found elsewhere: Aside from stromatolites and other microbial trace fossils, which may make up entire beds, fossils tend to be uncommon in the Prairie du Chien Group. The fossil assemblage includes sponge spicules (Clement 1935), possible stromatoporoid sponges (Powell 1935), brachiopods, polyplacophorans, monoplacophorans (Stauffer and Thiel 1941), bivalves (Powell 1935), nautiloids, gastropods, trilobites, echinoderms, conodonts, stromatolites, and invertebrate trace fossils (Stauffer and Thiel 1941). Gastropods are the most abundant body fossils (Clement 1935). Heller (1956) reported fossils in the Oneota Formation to be distributed in two zones, one 4.5 to 12 m (15 to 40 ft) above the base dominated by brachiopods and trilobites found in chert nodules, and a second around 18 m (60 ft) below the top dominated by mollusks. Fossils are less abundant in the overlying units, except for stromatolites, and body fossils are more frequently molds and casts in dolostone (Heller 1956). Dolomitization of the Prairie du Chien Group has reduced many body fossils to molds, which can be abundant (Ryan Clark, Iowa Geological Survey, pers. comm., June 2024).

The Prairie du Chien Group is noted as fossiliferous in the area of the Yellow River drainage basin, with stromatolites reported as a feature (Witzke and Anderson 2006). Calvin (1892) described a small assemblage of mollusks (nautiloids, monoplacophorans, and gastropods) collected from Allamakee and Clayton Counties; no stratigraphy within the Prairie du Chien Group is noted. Furnish (1938) described Oneota Formation conodonts from a locality in Allamakee County; the specified location of five miles north of Marquette would put it just north of EFMO (note that the provided township/section/range coordinates of T90N, R3W, section 17 would put it southwest of Marquette in Clayton County and therefore are assumed to be erroneous). Farther north, in the area from Church to Lansing, Witzke and McKay (1987) reported brachiopods, gastropods, microbial laminations or stromatolites, and burrows in the Coon Valley Member, stromatolites, burrows, and general bioturbation in the rest of the Oneota Formation, and snail molds and stromatolites in the Shakopee Formation.

St. Peter Sandstone (Middle–Upper Ordovician)

Description: The St. Peter Sandstone is a notably pure quartz sandstone (Webers 1972b). In the Yellow River drainage basin, it is composed of fine- to medium-grain quartz sand with some shale and conglomerate near the base and a small quantity of clay in the upper strata (Witzke and Anderson 2006). It is generally poorly consolidated except for the top bed (Witzke and Anderson 2006), but as elsewhere exposures may be case-hardened by weathering into durable surfaces (pers. obs., 13/14 November 2023). Generally the lower portion forms slopes and the upper portion forms ridges in this area (Witzke and Anderson 2006), a pattern that is borne out in EFMO; there is an interval near the upper contact that forms human-scale waterfalls, “lips”, and chutes, as visible in the higher elevations of the South Unit and Heritage Addition (Figure 13), and there is a prominent sandstone bluff with exposed face immediately below the Marching Bear Group (pers. obs., 13/14 November 2023) (Figure 14). The slope break (Figure 15) occurs at roughly 300 m (984 ft), and the concealed contact with the recessive overlying Glenwood Formation is just above. The thickness of the St. Peter Sandstone varies greatly in the area due to variation in pre-St. Peter erosion of the Prairie du Chien Group, from 9–69 m (30–225 ft), averaging 11–18 m (35–60 ft) (Witzke and Anderson 2006); the thickness at EFMO would appear to be generally as thick or somewhat thicker than average, around 20 m (66 ft). The St. Peter Sandstone is naturally off-white, but oxides can stain it bright colors (Calvin 1895); Pictured Rocks (“Painted Rocks” of McGee 1891) in Pikes Peak State Park is a notable location for stained St. Peter Sandstone.



Figure 13. Knickpoints in the St. Peter Sandstone at EFMO, Heritage Addition. **A.** Looking up into a ravine with several “steps” visible. **B.** Looking down a narrow steep chute in a different ravine. NPS / JUSTIN TWEET



Figure 14. A steep St. Peter Sandstone bluff in the South Unit. NPS / JUSTIN TWEET



Figure 15. Part of the St. Peter slope break in the southern South Unit. NPS / JUSTIN TWEET

The depositional processes and setting of the St. Peter Sandstone have long been debated, with different geologists preferring wind-driven deposition, marine deposition, or terrestrial deposits reworked by marine processes (Mai and Dott 1985). Historically, the most popular view is that the sandstone was deposited in coastal and shallow marine settings during a transgression that eventually led to the deposition of the Glenwood Formation (Mazzullo and Ehrlich 1987). More recent reports have suggested a combination of eolian and marine processes (Mai and Dott 1985), such as continental sand sheets laid down by wind and rivers, then reworked by the rising sea (Dott et al. 1986), or sand deposited in shallow marine settings after being transported primarily by wind (Mazzullo and Ehrlich 1980, 1983, 1987). The absence of terrestrial vegetation during the Middle Ordovician made wind a much more effective force for erosion and transportation (Dott et al. 1986; Mazzullo and Ehrlich 1987). The formation may represent a coastal and shallow marine setting similar to the tidal flats of the North Sea, with distinct depositional areas corresponding to sand flats, upper to lower shorefaces, and the nearshore shelf. Shoreface rocks are the major hosts of body fossils. Nearshore shelf rocks can have burrows and bioturbation. Overall, the formation is composed of stacks of these coastal and shelf rocks, which record the fluctuation of the shoreline (Mazzullo and Ehrlich 1987). The formation is thus a composite of multiple cycles of sea-level change (Witzke and Metzger 2005). Southern Hemisphere trade winds blew over the sea (Dott et al. 1986).

Deposition of the formation began during the Middle Ordovician, based on conodont species, and continued into the Late Ordovician (Mossler 2008). The lower contact with the Prairie du Chien Group is a disconformity, representing the transition between the great Sauk and Tippecanoe sea-level cycles (Mossler 2008). The disconformity was a time of erosion, later filled by St. Peter deposits as sea level rose again (Witzke 2000). The placement and nature of the upper contact with the Glenwood Formation are controversial. The most recent assessment by the Minnesota Geological Survey described the contact as a brief pause in deposition without much erosion, not a true disconformity (Mossler 2008).

Fossils found within EFMO: None to date. Weathering and case-hardening obscure the surficial details of the monument's exposures.

Fossils found elsewhere: Fossils are generally uncommon in the St. Peter Sandstone, with the exception of burrows such as *Skolithos* (Mossler 2008). Both Calvin (1895; Allamakee County) and Leonard (1906; Clayton County) reported no St. Peter Sandstone fossils in their study areas. Witzke (2000) observed burrows at Pikes Peak State Park. The only significant body fossils reported from this region are the molds and casts described in Sardeson (1896) from around St. Paul, Minnesota. These include bryozoans, brachiopods, monoplacophorans, bivalves, nautiloids, and gastropods (Sardeson 1896; Sloan 1987a). Somewhat closer to EFMO, Sinclair (1942) described a St. Peter Sandstone conulariid from Faribault, Minnesota. Conodonts are also known from various locations (Witzke and Metzger 2005; Mossler 2008).

Glenwood Formation (Upper Ordovician)

Description: The Glenwood Formation (sometimes called the Glenwood Shale) is the lowest unit in a lower Upper Ordovician sequence that is mapped undivided and poorly exposed at EFMO, also

including the succeeding Platteville and Decorah Formations. The Glenwood Formation is a thin (0.9–3 m [3–10 ft]) unit composed primarily of green-gray noncalcareous shale, partly phosphatic, sometimes sandy or silty, with minor siltstone and sandstone (Witzke and Anderson 2006). No outcrops were observed within EFMO, and from observations elsewhere this unit is rarely seen except where sandwiched by well-exposed beds of the St. Peter Sandstone and Platteville Formation. Early publications on regional geology included it as an unnamed basal shale member of the overlying "Trenton Limestone" (e.g., Calvin 1895; Leonard 1906). Even after its formal naming, it was sometimes included as the basal member of the Platteville Formation (e.g., Steinhilber et al. 1961).

The Glenwood Formation is a marine formation. It is considered transitional between the shoreward setting of the St. Peter Sandstone and the offshore carbonate rocks of the Platteville Formation (Webers 1972a). The depositional setting was probably a shallow marine shelf or coastal lagoon (Mossler 1985). The rate of deposition was low, with sediment input affected by the rising sea level (Schutter 1996). Sediments arrived from the Transcontinental Arch to the west and northwest (Austin 1972; Webers 1972a, 1972b). Some lateral "bulges" in its deposition may reflect proximity to rivers (Webers 1972a).

Deposition occurred during a brief portion of the early Late Ordovician (Witzke and Metzger 2005; Mossler 2008). Its upper and lower contacts have been problematic. The equivocal nature of the contact with the St. Peter Sandstone has already been discussed. The contact with the Platteville Formation has sometimes been described as disconformable, but there is no evidence for this (Mossler 2008). In fact, the age of the Glenwood–Platteville contact probably varies by location, because the Glenwood Formation of some areas is equivalent in age to parts of the lower Platteville Formation in others, and sometimes is present at the expense of these Platteville Formation rocks (Sloan 1972, 1987b; Mossler 1985). This indicates that the conditions that led to the deposition of the Platteville Formation arrived later in some areas than others, so more shale was deposited before Platteville deposition began.

Fossils found within EFMO: None to date.

Fossils found elsewhere: The Glenwood Formation is sparsely fossiliferous, except for microfossils such as scolecodonts and conodonts (Witzke 2000). It is likely that many fossils were destroyed by leaching and dolomitization (Schutter 1996; Mossler 2008). Types of fossils reported from the Glenwood Formation include sponge spicules (Mossler 2008), conulariids, bryozoans, brachiopods, bivalves, gastropods, scolecodonts, trilobites (Stauffer and Thiel 1941; Mossler 2008), ostracodes (Johnson et al. 1991; Mossler 2008), echinoderms (Schutter 1996; Mossler 2008) such as crinoids (Johnson 1988), graptolites (Schutter 1996), conodonts (Stauffer and Thiel 1941; Mossler 2008), invertebrate burrows, fecal pellets, and chitinozoans (Mossler 2008). Witzke and McKay (1987) observed burrows in the Glenwood Formation north of EFMO in their Church–Lansing section.

Platteville Formation (Upper Ordovician)

Description: The Platteville Formation (sometimes called the Platteville Limestone) is the most resistant unit of the Glenwood–Platteville–Decorah sequence and is composed primarily of limestone and dolostone. The basal interval, the Pecatonica Member, is composed of sandy dolostone. The overlying strata, in the McGregor Member, are composed of fossiliferous limestone with some shaly beds (Witzke and Anderson 2006). Beds in this member are wavy-bedded and often contain well-preserved fossils (Witzke 2000). Together, they are about 8.5–13 m (28–43 ft) thick, increasing in thickness to the south (Witzke and Anderson 2006). Within EFMO, the Platteville Formation is almost entirely covered by surficial deposits except for isolated stair-like exposures (Figure 16) and ravine-side outcrops (Figure 17). Despite the rarity of outcrops, its presence is easily noted by characteristic loose stones. These stones are frequently fossiliferous (pers. obs., 7 July and 13/14 November 2023). Mossler (2008) describes the McGregor Member in neighboring southeastern Minnesota as including limestone beds separated by thin shale partings, which appears to be borne out by the limited outcrops in EFMO. Beds here are approximately 15 cm (6 in) thick.



Figure 16. A series of Platteville Formation “natural stairs”. Note the thinner beds, unlike the poorly bedded St. Peter Sandstone. NPS / JUSTIN TWEET



Figure 17. The Platteville Formation is also exposed in ravine walls. NPS / JUSTIN TWEET

The Platteville Formation name was not introduced until the early 20th century, and older reports frequently call it the Trenton Limestone (e.g., McGee 1891; Calvin 1892; Leonard 1906). These reports also do not strictly divide the overlying rocks from it, so translating stratigraphic names may be tricky and is not helped by shifting classifications of the Decorah–Dunleith interval. In some ways, it can be easier to think of the Glenwood–Platteville–Decorah–Dunleith sequence as one "continuous" interval of marine deposition, taking place over a geologically brief timespan of a few million years, with differences in lithology due to changes in input of fine sediment, water depth, and distance to shore. Paleontologically there is significant (but not complete) overlap of fossil genera.

The Platteville Formation was deposited in open marine waters of normal salinity and oxygenation, mostly subtidal but above storm base and in the photic zone (Kolata 2021). This depositional setting has been compared to the carbonate platform of the Bahamas (Ojakangas and Matsch 1982). Deposition occurred in a shallow marine carbonate bank with abundant fossils representing the first widespread communities of immobile bottom-dwelling forms in the area. Conditions were generally stable, with the exception of higher-energy events recorded by thin shell beds. Fossils are not abraded, showing that they were not transported long distances, but they are disarticulated. Hard parts fell into a thin, limy ooze that later turned to limestone. Because large nautiloid shells (up to 25 cm [10 in] in diameter) are commonly found only partially preserved, the ooze was not thick enough to bury them completely (Webers 1972a, 1972b). Lithified seafloors, known as hardgrounds, formed

during periods of little to no deposition; one such bed is the top of the Pecatonica Member (Mossler 2008). Thin shale partings between limestone beds represent sediment settling after storms (Sloan 1972). Thicker shaly beds record episodes of uplift of the Transcontinental Arch (Webers 1972b). Dolomitization occurred during and after deposition, mostly the latter (Asquith 1967).

Deposition occurred during the Late Ordovician. The only numeric age date that can be used for reference is that for the Deicke K-bentonite near the base of the overlying Decorah Formation, representing a massive volcanic eruption off the eastern margin of North America (Kolata et al. 1996). It has recently been dated to 453.35 ± 0.10 Ma (Metzger et al. 2021). The contact with the Decorah Formation is a brief depositional hiatus (Mossler 2008), expressed as a hardground (Kolata 2021).

Fossils found within EFMO: The fossil assemblage of the Platteville Formation within EFMO is dominated by three groups: brachiopods, found as whole or fragmented shells; gastropods, best observed in cross-section; and crinoids, found as solitary columnals disarticulated from crinoid stems. Brachiopods are by far most abundant. Several groups are present in lesser abundance: horn corals, bryozoans, hyoliths, bivalves, nautiloid cephalopods, trilobites, and ostracodes as body fossils, and invertebrate trace fossils. Other groups are likely present but have not been identified. Single loose fossils have not been observed but are likely present; instead, fossils ranging from whole specimens to unidentifiable fragments are found in abundance in certain rocks, which can be called “hash plates” (Figure 18). More than two dozen taxa can be distinguished, and the assemblage appears to be typical for the Platteville Formation. See the “Taxonomy” and “Localities” sections below for more information.



Figure 18. A typical Platteville Formation hash plate featuring innumerable shell fragments. NPS / JUSTIN TWEET

It is possible, even likely, that some of the float fossiliferous cobbles observed in the field actually eroded from the overlying Decorah Formation or Dunleith Formation, particularly those with significant rounding (and therefore more transport). However, given their almost exclusive concentration in areas where the Platteville Formation is present at or near the surface, and their lithological and paleontological consistency with the Platteville Formation, a Platteville origin should be considered default unless there is evidence arguing against it. Potential contributions of the Decorah and Dunleith Formations are limited by various factors: The Decorah Formation is poorly resistant to weathering and, therefore, has less of a near-surface presence than the Platteville, and the Dunleith Formation is only mapped in small areas of EFMO.

It is also likely that occasional cobbles of fossiliferous Platteville Formation rock may be found distributed widely in EFMO as a result of erosion in the past, particularly south of the Yellow River based on the geography of the nearest source areas. Fossiliferous Prairie du Chien Group cobbles may also be present. It should be possible to distinguish fossiliferous cobbles from these two geologic units on the basis of lithology (particularly sand grains or chert in the latter) and fossil types

and preservation (apart from taxonomic differences such as no bryozoans, Prairie du Chien Group body fossils are often natural molds). Fossiliferous Platteville and younger Paleozoic cobbles can also be expected to make up a small fraction of stones in the Yellow River bedload and river gravel at the Sny Magill Unit.

Fossils found elsewhere: The Platteville Formation is a significantly fossiliferous unit and is noted as fossiliferous in the area of the Yellow River drainage basin (Witzke and Anderson 2006). Knowledge of the fossils in the area goes back to the Owen expedition; Shumard (1852) reported assemblages of bryozoans, brachiopods, bivalves, nautiloids, gastropods, and trilobites from locations around Prairie du Chien, although it is likely these are composites of the Platteville–Decorah–Dunleith based on the species reported. One interesting fossil, a well-preserved specimen of the trilobite *Ceraurus pleurexanthemus*, was found at a quarry in McGregor and described in Thomas (1926). Brower (2007) described the Platteville echinoderm assemblage of northeastern Iowa, including Allamakee County, as including six crinoid species (*Abludoglyptocrinus charltoni*, *Carabocrinus* sp., *Cupulocrinus plattevillensis*, *Ectenocrinus simplex*, *Merocrinus britonensis*, and *Porocrinus pentagonius*), a cyclocystoid, and plates of a rhombiferan cystoid. The McGregor Member of the area is noted for thin fossiliferous beds or horizons representing episodic concentrations of shells, perhaps generated by storms, with fossils such as horn corals, bryozoans, brachiopods, nautiloids, gastropods, trilobites, ostracodes, and crinoids (Witzke 2000).

Types of fossils known from the Platteville Formation over its outcrop belt in northeastern Iowa, southeastern Minnesota, Wisconsin, and northwestern Illinois include chlorophyte green algae (and apparently very early moss-like true land plants; Cardona-Correa et al. 2016), sponges, tabulate and rugose corals, conulariids, bryozoans, brachiopods, cornulitid "worm tubes", hyoliths, diverse mollusks (polyplacophorans, monoplacophorans and minor similar groups that may be monoplacophorans or gastropods, rostroconchs, bivalves, nautiloids, and gastropods), scolecodonts, trilobites, ostracodes, various echinoderms (sea stars, crinoids, paracrinoids, rhombiferan cystoids, cyclocystoids, echinoids, edrioasteroids, and possible holothuroids), graptolites, conodonts, various invertebrate burrows and other trace fossils, acritarchs, foraminifera, chitinozoans, red algae, and enigmatic cyclocrinitids (Winchell and Ulrich 1897 ["Lower Buff" and *Vanuxemia* beds]; Stauffer and Thiel 1941 [McGregor Member]; Mossler 2008; Kolata 2021; Stauffer and Thiel also report a eurypterid in a faunal list, but the specimens are poorly preserved [pers. obs., 10 December 2018] and are not mentioned in the stratigraphic section for the location cited on their card). The most abundant fossils include a few genera each of bryozoans, brachiopods, bivalves, nautiloids, gastropods, trilobites, ostracodes, crinoids, and trace fossils (Kolata 2021).

Galena Group: Decorah Formation (Upper Ordovician)

Description: The Decorah Formation (sometimes called the Decorah Shale) is a slope-forming unit that is not known to crop out within EFMO but should be present in the subsurface in high elevations in the western Heritage Addition and southern South Unit. A few of the loose blocks observed in the ravines and gullies in these areas resemble pieces from thin Decorah Formation limestone beds, but this identity was not confirmed. Based on observations elsewhere, the presence of this formation at or very near the surface would be indicated by greenish-gray soil with small fragments of thin, heavily

fossiliferous limestone. Extreme precipitation events at high elevations in the areas referenced above have the potential to strip surficial deposits and bring Decorah Formation strata and sediments to light. Witzke and Anderson (2006) divide the Decorah Formation into four members, in ascending order the Carimona, Spechts Ferry, Guttenberg, and Ion Members, but the lack of exposures in EFMO limit the usefulness of this division for paleontological resource management. The Decorah Formation is composed of green-gray lime-rich shale with occasional beds of nodular to wave-bedded limestone and is roughly 12–14 m (40–47 ft) thick (Witzke and Anderson 2006). Limestone becomes a more prominent component going south in the map area of Witzke and Anderson (2006), which is consistent with the general regional trend of shale being replaced by limestone farther from the sediment source in central Minnesota (e.g., Witzke and Ludvigson 2005; Mossler 2008).

The relationship of the Decorah Formation and overlying Dunleith Formation is complex and beyond the scope of this document to detail comprehensively. Although a shaly interval between limestone intervals in this section of the Ordovician of northeastern Iowa and adjoining states has long been recognized, in practice drawing contacts and subdividing strata varies between authors and at locations. Apart from the overall trend mentioned above, changes in mud input must have varied on a small scale, both geographically and in time. As noted in the "Platteville Formation" section, it can be helpful to think of the Glenwood–Platteville–Decorah–Dunleith interval as a whole rather than as discrete units.

The Decorah Formation is thought to have been deposited in a shallow nearshore marine setting with warm water and normal salinity. The water was at least relatively clear, given the abundance of filter-feeders. Episodic high-energy conditions, reflected in the fossil-rich limestone beds, could be due to storms. Fossils are broken and disarticulated but not sorted, indicating that low-energy conditions prevailed most of the time, and partially preserved large nautiloids (a phenomenon also seen in the Platteville) illustrate the relative thinness of the ooze on the seafloor (Webers 1972a, 1972b). Immense volcanic eruptions on the eastern margin of North America are represented by bentonite beds found at several levels. The two lowest, the Deicke K-bentonite near the base and the slightly higher Millbrig K-bentonite, have recently been dated to 453.35 ± 0.10 Ma and 453.36 ± 0.14 Ma (Metzger et al. 2021); with dates this close, the slightly older date for the slightly higher Millbrig is within uncertainty.

Sediment arrived from the Transcontinental Arch to the west and northwest (Austin 1972; Webers 1972b). The arch underwent uplift during this time, possibly in response to the tectonic activity along the eastern margin of the continent that was also fueling the ash-spewing volcanic eruptions. As the source rocks eroded away, shale input decreased and carbonate deposition resumed in correlation to the distance from the arch. This explains why the Decorah Formation has a wedge-shaped profile and is so thick nearer the arch, and why the top of the Decorah Formation is younger nearer the arch than in areas to the southeast, where it is replaced by limestones of the Cummingsville Formation (Sloan et al. 2005) or the equivalent lower Dunleith Formation (Witzke and Ludvigson 2005). The upper contact is conformable but time-transgressive, as noted much higher and younger to the north (Mossler 2008).

Fossils found within EFMO: None confirmed to date, but some fossils identified as Platteville may actually have eroded from the Decorah Formation (see comment in "Platteville Formation" section).

Fossils found elsewhere: The Decorah Formation is noted as fossiliferous in the area of the Yellow River drainage basin, with brachiopod-rich beds reported as a feature (Witzke and Anderson 2006). Fossils have long been noted as a major part of this unit in the area; both Calvin (1895; Allamakee County) and Leonard (1906; Clayton County) described the shale interval now known as the Decorah Formation as fossiliferous. There is a notable zone featuring the hemispherical or "gumdrop" bryozoan *Prasopora* near the top in the Ion Member (Witzke 2000). Witzke and McKay (1987) reported *Prasopora*, various brachiopods, trilobites, and burrows in the Decorah Formation of their Church–Lansing section north of EFMO.

Types of fossils known from the Decorah Formation include dasycladacean green algae, sponges and possible sponges, rugose and tabulate corals, conulariids, bryozoans, brachiopods, cornulitid "worm tubes", hyoliths, diverse mollusks (monoplacophorans and scenellids, rostroconchs, bivalves, nautiloids, and gastropods), scolecodonts, trilobites, ostracodes, various echinoderms (sea stars, crinoids, cystoids, edrioasteroids, and rare stylophorans as described in Kolata and Jollie [1982]), graptolites, conodonts, invertebrate trace fossils, chitinozoans, red algae (Winchell and Ulrich 1897 [*Stictoporella* bed through "Fucoid and *Phylloporina*" bed]; Stauffer and Thiel 1941 [Spechts Ferry and Decorah Formation]; Mossler 2008), and the apparent cyanobacteria *Gloeocapsamorpha prisca* (Sloan et al. 1987).

Galena Group: Dunleith Formation (Upper Ordovician)

Description: The Dunleith Formation is a resistant limestone unit and the stratigraphically highest and youngest bedrock formation mapped within EFMO (Witzke and Anderson 2006). It is mapped in areas of the western Heritage Addition and southern South Unit (Witzke and Anderson 2006) but is not known to be exposed at the surface. Some shale is present in the lower part, and some of the limestone has been altered to dolostone; chert is also locally abundant (Witzke and Anderson 2006); chert has often diagenetically replaced carbonate minerals and fossils after burial. It is the equivalent of the Cummingsville and overlying Prosser Formations in Minnesota (Witzke and Ludvigson 2005; Mossler 2008), and by extension its lowest strata are time-equivalent to the uppermost part of the thickest Decorah Formation sections. Going south in Iowa this continues, with beds equivalent to the Ion Member of the Decorah Formation becoming the lowest two members of the Dunleith Formation (Mossler 2008). Because only very small areas of EFMO are mapped as the Dunleith Formation (Witzke and Anderson 2006), and these areas do not display any significant topography, it can be assumed that only the lower part of the formation may be present in EFMO, perhaps the basal 6–12 m (20–40 ft). Another marine carbonate like the Platteville Formation, the Dunleith Formation is noted for numerous hardgrounds, indicating pauses in deposition (Witzke 2000).

Fossils found within EFMO: None confirmed to date, but some fossils identified as Platteville may actually have eroded from the Dunleith Formation (see comment in "Platteville Formation" section).

Fossils found elsewhere: The Dunleith Formation is noted as fossiliferous in the area of the Yellow River drainage basin, and mottled bedding from invertebrate burrows is noted as one feature (Witzke and Anderson 2006). The paleontology of the formation is relatively understudied (Witzke and Glenister 1987) but is similar to that in the underlying Decorah and Platteville Formations. One key difference is the presence of receptaculitids. In particular, the lower Dunleith is noted for a zone of *Fisherites* (formerly *Receptaculites*) (Steinhilber et al. 1961). *Fisherites*, horn corals, brachiopods, gastropods, and crinoids are visible in this formation at Pikes Peak State Park (Witzke 2000). The Dunleith echinoderms of northeastern Iowa, particularly crinoids, have been documented in a series of publications (e.g., Brower and Strimple 1983; Brower 1992a, 1992b, 1994, 1995a, 1995b, 1996, 1999); interestingly, "E. Orr (deceased)" is acknowledged as a collector in many of these papers. Witzke and Glenister (1987) reported a fauna of receptaculitids, dasycladacean green algae, sponges, corals, bryozoans, brachiopods, bivalves, nautiloids, gastropods, trilobites, ostracodes, echinoderms, and burrows and borings in northeastern Iowa. Brachiopods, mollusks, trilobites, and echinoderms are particularly abundant. Similar fossils were observed by Sloan et al. (1987).

For reference, in Minnesota, the Cummingsville Formation (lower Dunleith) includes receptaculitids, dasycladacean green algae, sponges, tabulate and rugose corals, bryozoans, brachiopods, monoplacophorans and scenellids, bivalves, nautiloids, gastropods, cornulitid "worm tubes", trilobites, ostracodes, crinoids, and trace fossils (Winchell and Ulrich 1897 [*Clitambonites* bed]), with rare conodonts (Mossler 2008). Overall, fossils are abundant in this formation in Minnesota but are difficult to extract (Mossler and Benson 2006).

Quaternary Rocks and Sediments (Pleistocene–Holocene)

Description: Except for vertical bluff surfaces and a few areas of bare rock in ravines, EFMO's land surfaces are draped with unconsolidated Quaternary deposits, including soils, pond deposits, floodplain deposits, and deposits from mass wasting.

Fossils found within EFMO: Microfossils recovered from a core taken from Founders Pond (Figure 19) have been used to describe the local environment and climate over the past 9,000 years (McGuire Bogen and Hotchkiss 2007). Material including spores and pollen of clubmosses, spikemosses, conifers, and angiosperms, seeds, peat, charcoal, gastropod shells and other shells, diatoms, and unspecified algae were recovered. These materials show ecosystem shifts from prairie, to oak savanna with a mosaic of habitats, to greater tree cover. Charcoal data was collected from the portion of the core representing the period approximately 2,400 to 600 calibrated years before present ("present" being the year 1950 in radiocarbon convention), bracketing the building of the mounds. Charcoal tapers off after 1,740 calibrated years before present as trees became more abundant, suggesting a more open, fire-prone setting when people built the earliest mounds, becoming more forested during the later history of mound-building (McGuire Bogen and Hotchkiss 2007). Similar deposits may be present elsewhere in EFMO. Because the middle Holocene represents an extended warm period, these fossils are also of interest for showing a potential climate future at EFMO.



Figure 19. A view of Founders Pond. NPS / JUSTIN TWEET

Fossiliferous Paleozoic clasts are undoubtedly present in the fluvial deposits of EFMO and may include material sourced from formations not exposed in the monument. However, general fossil content should be similar to what is known from the Platteville. The most likely sources would be the resistant Upper Ordovician rocks of the area due to the durability of the rock, abundance of fossils, and source proximity. Local fossiliferous sandstone and shale units such as the upper Cambrian Tunnel City Group exposed in the Mississippi River Valley upstream are less durable, rocks of the Prairie du Chien Group are durable and local but sparsely fossiliferous, and younger Devonian limestones are resistant and fossiliferous, but found more distantly.

Fossils found elsewhere: A project similar to that at Founders Pond focused on the Roberts Creek Basin (Baker et al. 1996), 24 km (15 mi) west of the Sny Magill Unit. This project differed in that a pond was not the source; instead, cut-bank sections of alluvial fill were sampled. These sections cover a slightly longer time frame, reaching the latest Pleistocene. Aside from pollen and spores of bryophytes and vascular plants, there were wood and other plant macrofossils and a variety of invertebrates, such as mollusks, beetles and other insects, spiders, mites, and ostracodes (Baker et al. 1996).

Fossils of Pleistocene megafauna (e.g., mammoths, sloths, horses, saber-toothed cats, etc.) are present in northeastern Iowa. Hay (1914, 1924) noted a few occurrences of mammoths or mastodons in Allamakee and Clayton Counties, including in Wagner Township, approximately 21 km (13 mi) west of the Sny Magill Unit; 3 km (2 mi) east of Garber, approximately 22 km (14 mi) south of the Sny Magill Unit; and 6.5 km (4 mi) north of Postville on the banks of the Yellow River, approximately 27 km (17 mi) west-northwest of the bulk of EFMO. Gastropod fossils are present in loess deposits but appear to be “practically absent” north of 42° 30′ N (McGee 1891), well south of EFMO. Indeterminate bird and mammal bones have been found in caves in northeastern Iowa (McGee 1891) but have not been reported from the few small cave features in EFMO.

Taxonomy

See Appendix A for full lists of taxa.

Fossil Plants

The EFMO paleobotanical record is confined to materials recovered in the Founders Pond core, as reported in McGuire-Bogen and Hotchkiss (2007). Both microfossils (in the form of palynomorphs, organic microfossils such as spores and pollen) and macroscopic fossils were recorded. In the microfossil realm, more than three dozen palynomorph forms were identified, representing clubmosses and spikemosses (as spores) and conifers and angiosperms (as pollen). A mix of aquatic, herbaceous, grass, shrub, and tree taxa was found. The macroscopic record was not discussed in detail and consisted of woody fragments, peat, charcoal, and seeds; only the seeds have much potential for further taxonomic identification.

Fossil Invertebrates

Aside from shells including gastropod shells observed in Prairie du Chien Group chert and reported from Holocene sediments at Founders Pond, all of the invertebrate fossils observed at EFMO that can be assigned to a geologic unit come from the Platteville Formation. As mentioned, it is possible, even likely, that some of the loose fossiliferous stones derive from the slightly younger overlying Decorah Formation or Dunleith Formation, but these units have similar fossils to the Platteville, unsurprising because together the three units represent a few million years of deposition under similar conditions. Kolata (2021) is an excellent reference for Platteville Formation fossils, with hundreds of fossil taxa illustrated and described.

Fossil hash, composed primarily of shell fragments, is found abundantly throughout the Platteville Formation rocks in EFMO (Figure 18). Some of this material is identifiable to a broad group, but much is not. Identifying fragments and poorly preserved material is complicated by weathering and how the plane of the exposure intersects the fossil (Figure 20); horn corals, for example, show up as a "starburst" when seen in cross-section perpendicular to the long axis, a "V" or "U" when exposed tangentially, and anything in between depending on the angle. With this in mind, when dealing with an unfamiliar fossil, it is best to start by picturing how common fossils may look when exposed at odd angles and/or in cross-section, and then go on to rare or unique fossils after the common possibilities are eliminated.



Figure 20. The unusual outline on the right, indicated by a red arrow, is a cross-section through a strongly ribbed brachiopod with a central depression (sulcus), probably a large *Rostricellula* (see below). NPS / JUSTIN TWEET

Dozens of fossiliferous stones attributed to the Platteville Formation were observed. In terms of abundance, brachiopods were by far the most frequently observed fossil type, followed distantly by gastropods and crinoid columnals. After this, there were several good examples of horn corals. Next, there were a handful of potential bryozoans, nautiloids, trilobites, and ostracodes, with one or two good examples of each. A few rocks had cross-sections that represent bivalves, which are likely more common (it can be difficult to distinguish a poorly preserved bivalve fragment from a poorly preserved brachiopod fragment). One block had an internal cast of a hyolith. Finally, there were some fragments that have not been identified and which may represent other groups.

Phylum Cnidaria (jellyfish and corals)

Most Paleozoic coral fossils belong to one of two extinct orders: Tabulata (tabulate corals) and Rugosa (rugose corals). To date, only solitary rugose corals (horn corals) have been observed at EFMO in the Platteville Formation, but colonial rugose corals or tabulate corals may eventually be found there. Solitary rugose corals are also called “horn corals” because most of them are pointed conical fossils that resemble animal horns. Tabulates and colonial rugose corals can usually be distinguished by the sizes of the living chambers of the colonies, also known as corallites (less than a few millimeters in diameter in tabulates [less than a fifth of an inch], substantially larger in rugose corals), and the structures in the chambers (simple or no vertical internal structures in tabulates, generally more complex in rugose corals). Several well-preserved examples of horn corals were encountered at EFMO (Figure 21). Kolata (2021) included only one genus and species of horn corals (*Lambeophyllum profundum*), but other older lists (Winchell and Schuchert 1895; Stauffer and Thiel 1941) also include several species of the very similar *Streptelasma*, and there does not appear to be a

compelling reason to go beyond undetermined Rugosa here. Most of the EFMO fossils identifiable as horn corals show the exterior at an oblique angle, frequently with partial weathering of the surface, which gives them spiky outlines.

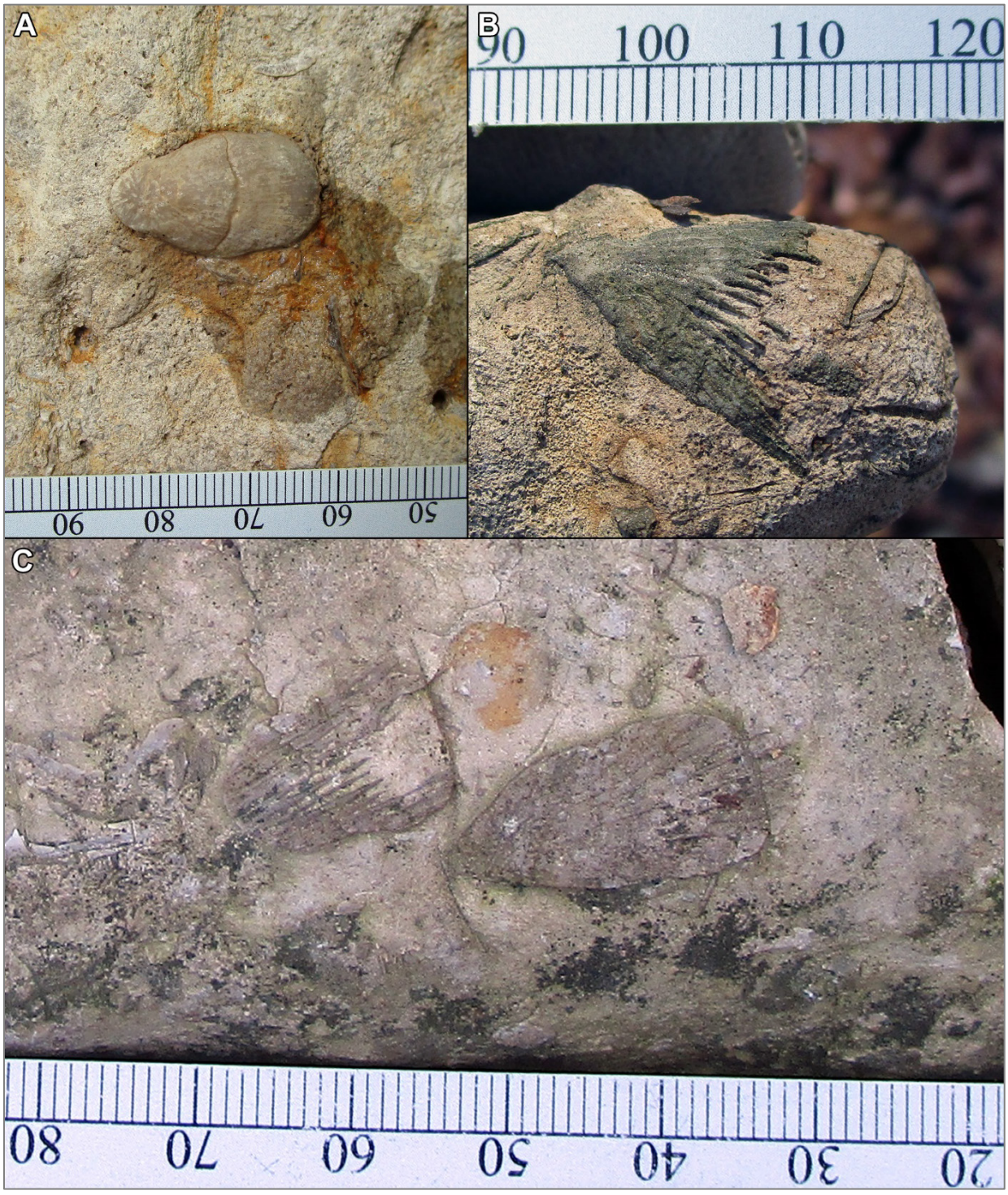


Figure 21. A selection of Platteville Formation horn corals observed in EFMO. Preservation quality varies. These are all side views, either orthogonal or slightly oblique. NPS / JUSTIN TWEET

Phylum Bryozoa (moss animals)

Bryozoans are microscopic animals that build larger, macroscopic colonies and have a substantial fossil record. Individual animals are typically on the order of 0.5 mm (0.02 in) long and feed with a filter-feeding apparatus called a lophophore. Their colonies are sometimes mistaken for coral colonies, but the living chambers of bryozoans are much smaller than those of corals, resembling pores or pinpricks (sub-millimeter scale versus millimeter to centimeter scale). Because of their structural variability, bryozoans are difficult to identify to genus or species without making thin sections, so it is often more helpful to think of them in terms of shapes. Bryozoan colonies may have a variety of shapes, such as stem- or branch-like (which can be mistaken for bones or plant fossils), domes, mesh-like or lacy, or irregular. Aside from dome-like colonies or encrusting colonies, finding a complete, unbroken example is rare. At EFMO, at least two colony forms can be recognized: a stem-like form (Figure 22) and a much rarer form with a mesh-like surface (only one small example was observed, so it may represent part of a more frond-like form or a broad flat structure). Large specimens were encountered infrequently, and in general bryozoan fragments may be difficult to spot and recognize among the myriad of fragments in a hash plate. A tell-tale sign for bryozoan “twigs” is the presence of the pinpricks or pores mentioned above.

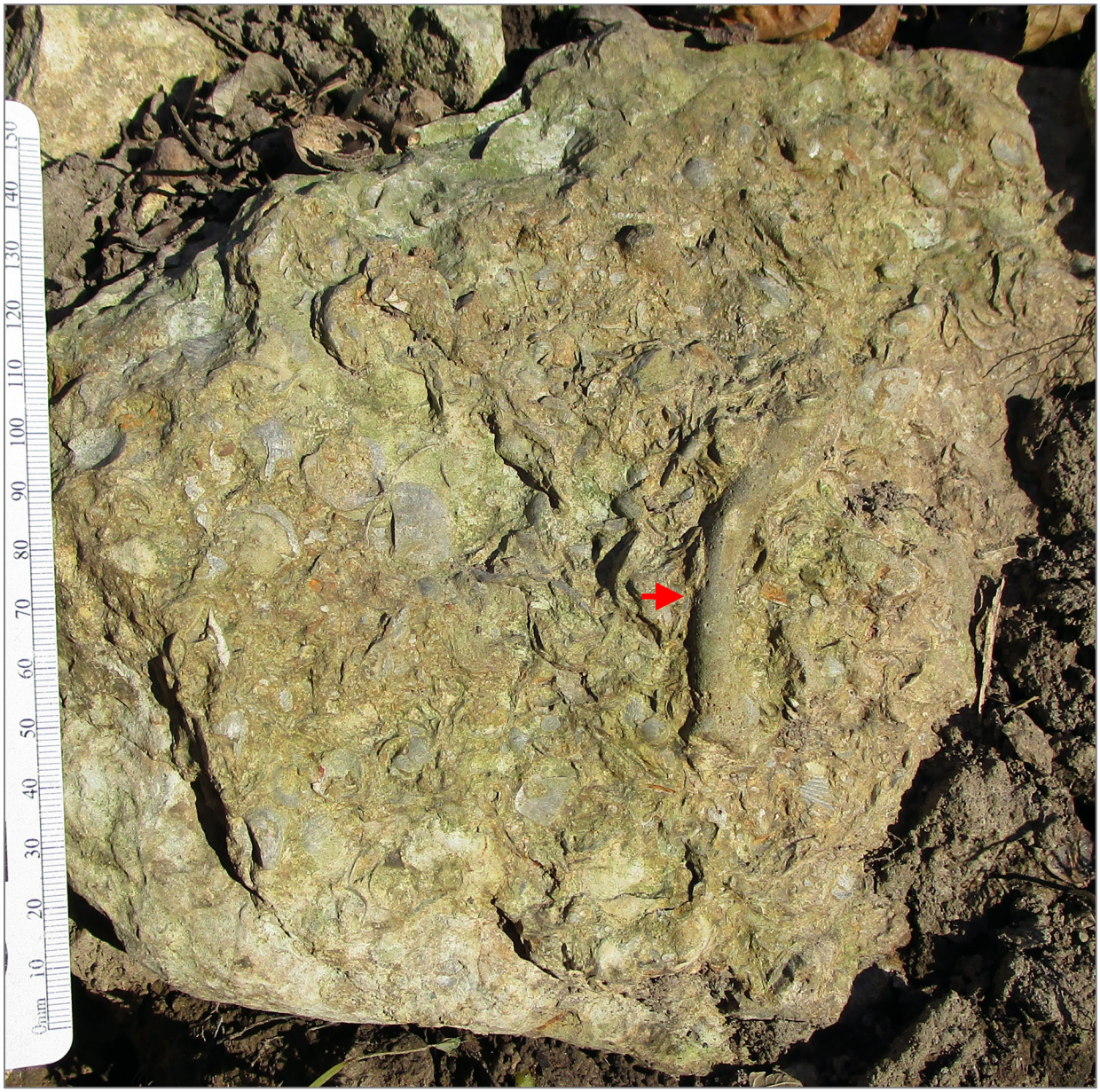


Figure 22. A large stem-like bryozoan fragment (indicated by a red arrow) among brachiopod shells of varying completeness. NPS / JUSTIN TWEET

Phylum Brachiopoda (lamp shells)

Brachiopods are shelled, sessile, filter-feeding marine invertebrates that resemble bivalve mollusks, but have much different internal anatomies and valve articulations. Like bryozoans, brachiopods feed using a lophophore, in their case supported by a mineralized brachidium that is occasionally preserved in fossils. Brachiopod shells can generally be distinguished from bivalve mollusks by symmetry. A single undistorted brachiopod shell (valve) has a line of symmetry running perpendicular to the hinge line, showing the left and right sides as mirror images, but the two valves are usually different shapes and sizes and, therefore, are not symmetric to each other. A single bivalve valve is usually asymmetric (less obvious for some groups such as scallops), but the two

valves are usually mirror images. This difference can be appreciated in cross-sections: most complete brachiopods exposed in cross-section have one valve much larger than the other, whereas a cross-section with equally sized valves is very likely to be a bivalve. Another noticeable difference between the two groups in Ordovician rocks is the surficial ornamentation: the brachiopods frequently have well-developed radial ribbing (costae) and sometimes have concentric growth marks, whereas the bivalves lack radial ribbing and the concentric growth marks are usually more prominent. Brachiopods also mineralize their shells using calcite, which has a higher preservation potential than the aragonitic shells of bivalves, so brachiopod fossils are often better preserved than bivalve fossils. During the Paleozoic Era, brachiopods were more abundant and diverse than bivalves, but now they are much more restricted. They are by far the most abundant fossils in the Platteville Formation at EFMO. Although it is easier to identify loose brachiopods than brachiopod shells in situ, several genera and species can be distinguished in rocks at EFMO:

Large (>2 cm or 0.8 in across the hinge line) roughly D-shaped shells with fine radiating ribs (appearing to form regular “bundles” bounded by slightly thicker ribs) belong to at least one species of large strophomenid (Figure 23). Several species are known from the Platteville and may not be distinguishable from partial or poorly preserved specimens, but at least one EFMO specimen is identifiable to *Strophomena* from the distinctive diamond-shaped internal muscle scars (Figure 23A). These shells may also be strongly concave or convex, characteristic of *Strophomena*, *Rafinesquina*, and particularly *Oepikina* (Figure 23C). Because of the thinness and curvature of the shells, they will sometimes weather as distinctive open D-shapes, with the center of the shell lost.

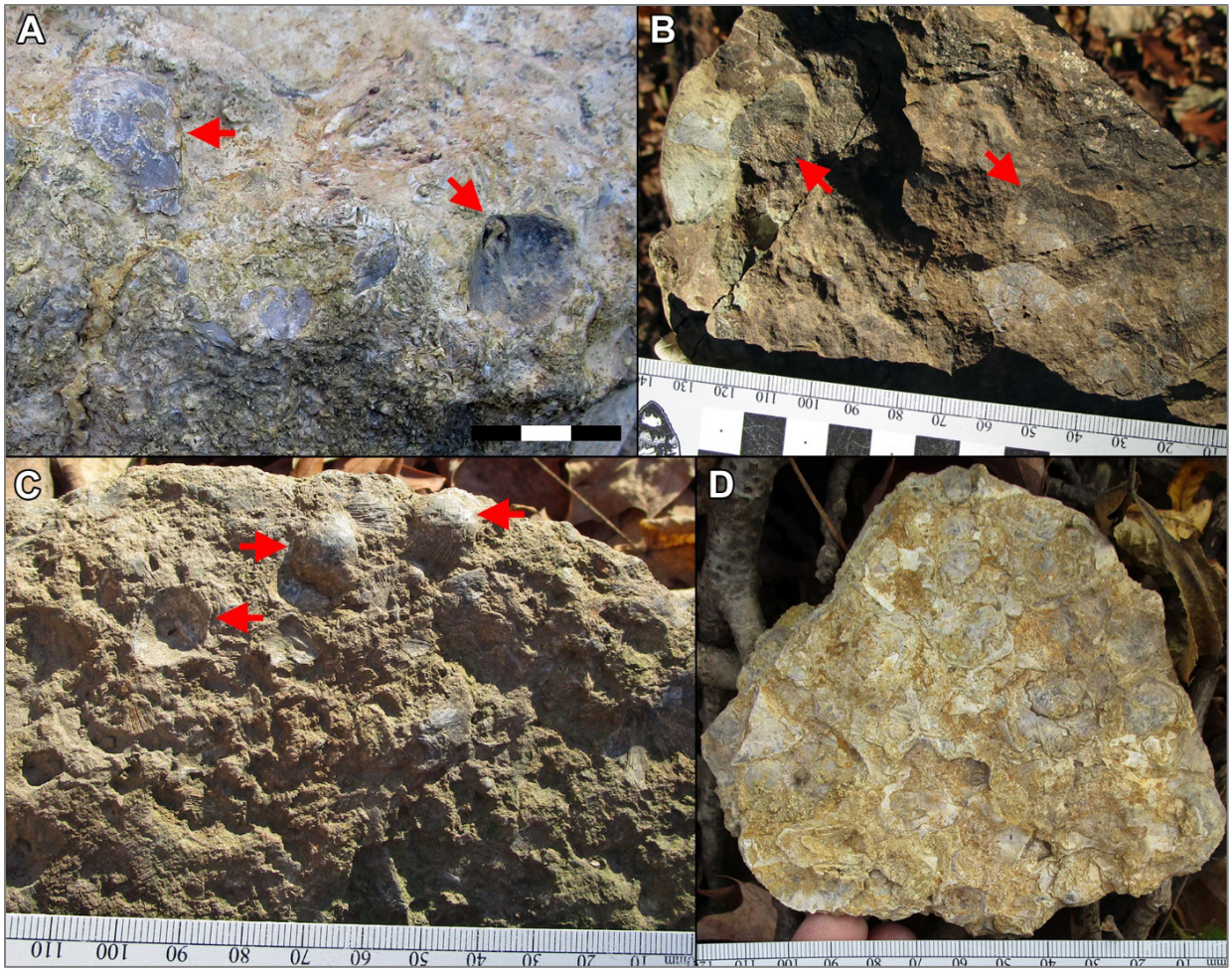


Figure 23. Various aspects of strophomenid brachiopods observed in EFMO. **A.** The cut-out diamond shapes on the two shells indicated by red arrows indicate a species of *Strophomena*. The scale bar is 3 cm (1.2 in). **B.** Several strophomenids are present here in various states of preservation; two of the best examples are indicated by red arrows. **C.** The light angle emphasizes the domed nature of the strophomenid shells, indicated by red arrows. **D.** Several strophomenids are visible here, mostly incomplete and poorly preserved. NPS / JUSTIN TWEET

An intermediate-sized bulbous smooth-shelled triangular form is most likely a *Camerella* with the ribbing at the margin concealed in the matrix or weathered smooth (Figure 24).

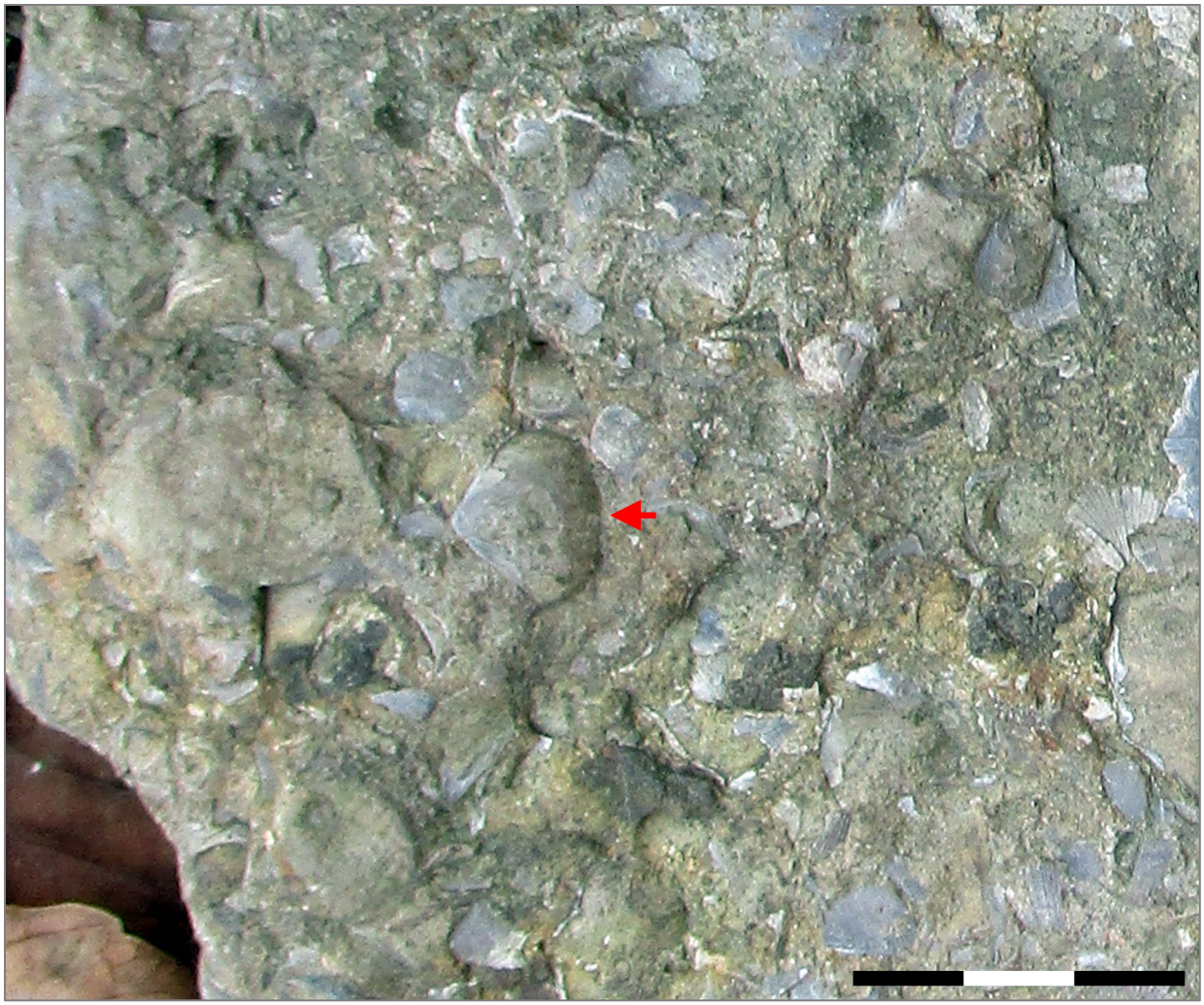


Figure 24. The relatively large triangular shell indicated by a red arrow is attributed to *Camerella*. The scale bar is 3 cm (1.2 in). NPS / JUSTIN TWEET

An intermediate-sized strongly ribbed form, close to D-shaped but with a projecting beak, and a steeply triangular profile represents the orthid *Hesperorthis* (no one specimen was complete enough and exposed properly to fully capture the shape) (Figure 25).

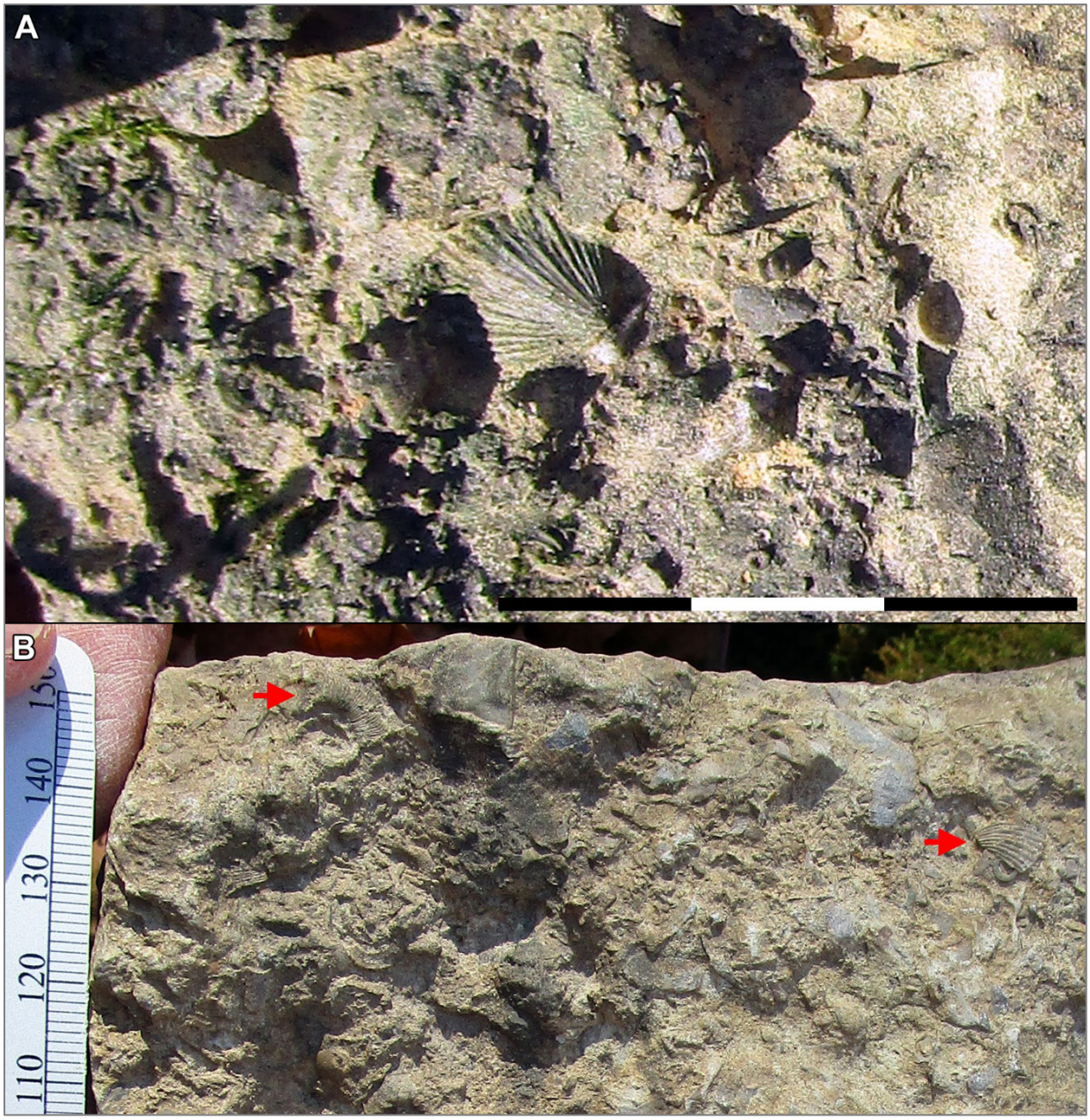


Figure 25. *Hesperorthis*. **A.** *Hesperorthis* is a distinctively ribbed brachiopod, resembling a folded hand fan. The scale bar is 3 cm (1.2 in). **B.** A flattened *Hesperorthis* (red arrow on the right); note also a partial whorl of a low-coiled gastropod with fine ridges in the upper left (*Ophiletina*). NPS / JUSTIN TWEET

An intermediate-sized form similar to *Hesperorthis* but with finer ribbing represents *Doleroides* (Figure 26).



Figure 26. The large central shell is *Doleroides*. Note also a small partial orthoconic nautiloid above and to the left, a fragment of a mesh-like bryozoan below, and a pentagonal crinoid columnal to the right (all indicated by red arrows). NPS / JUSTIN TWEET

A small (around 1 cm or 0.4 in across), nut-like, strongly ribbed form is likely *Rostricellula* (Figure 27; see also Figure 20 for cross-section).



Figure 27. *Rostricellula*. Although poorly preserved, it can be recognized by the combination of shape and strong ribbing. NPS / JUSTIN TWEET

Finally, one small (around 1 cm or 0.4 in across) broad D-shaped shell is interpreted as *Sowerbyella*, a small strophomenid (Figure 28).

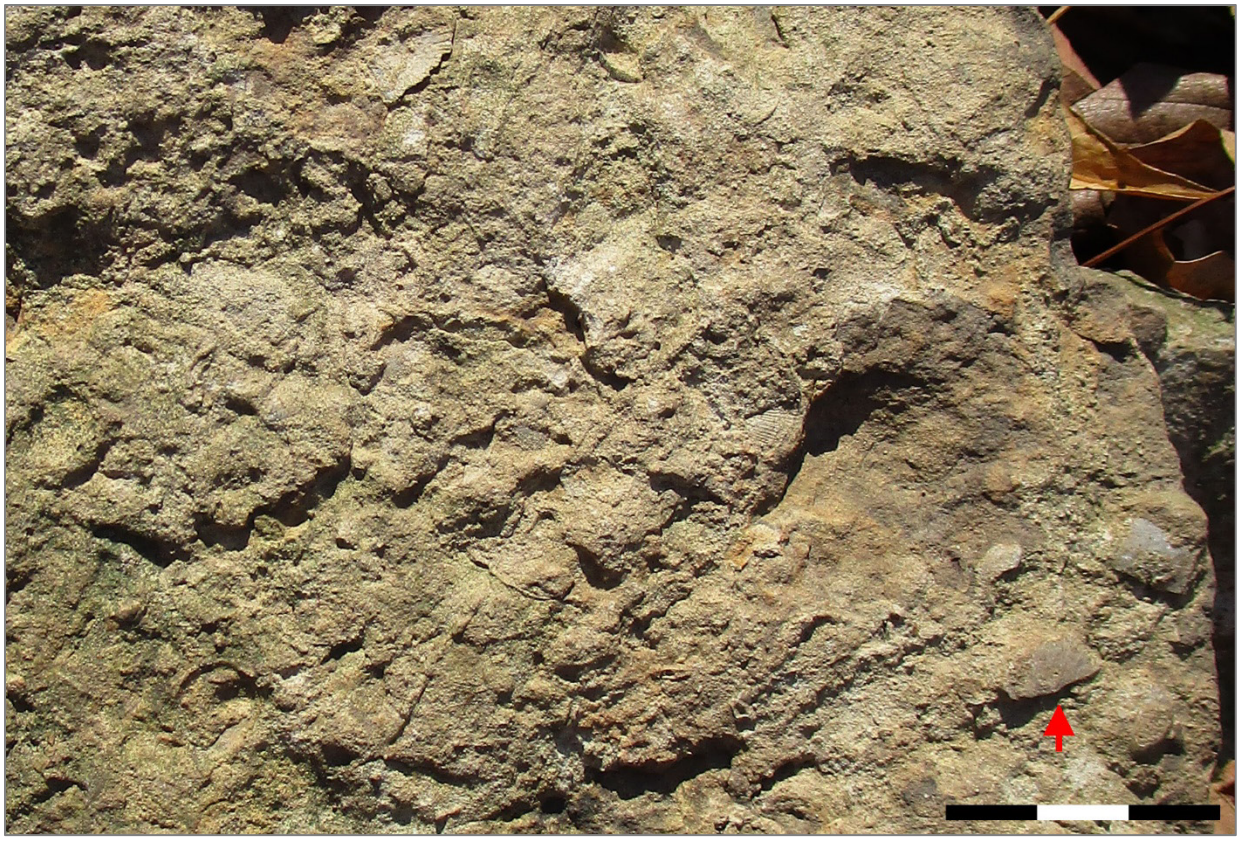


Figure 28. A fairly typical surface with shells of several brachiopods, including *Sowerbyella* highlighted near the lower right corner. The scale bar is 3 cm (1.2 in). NPS / JUSTIN TWEET

Other taxa are doubtless present but were not recognized due to poor preservation or weathering of characteristic anatomy. In many cases, shells had spalled from weathered blocks or had been dissolved by chemical processes long ago, leaving natural molds and casts of varying fidelity. Natural casts of the interior spaces of shells and other hard parts are known as steinkerns and are also a frequent mode of preservation for mollusks and horn corals. One example of an apparent brachiopod steinkern can be seen in Figure 29. The shape indicates an orthid such as *Doleroides* or *Hesperorthis*, but the pattern of ribbing is not evident.

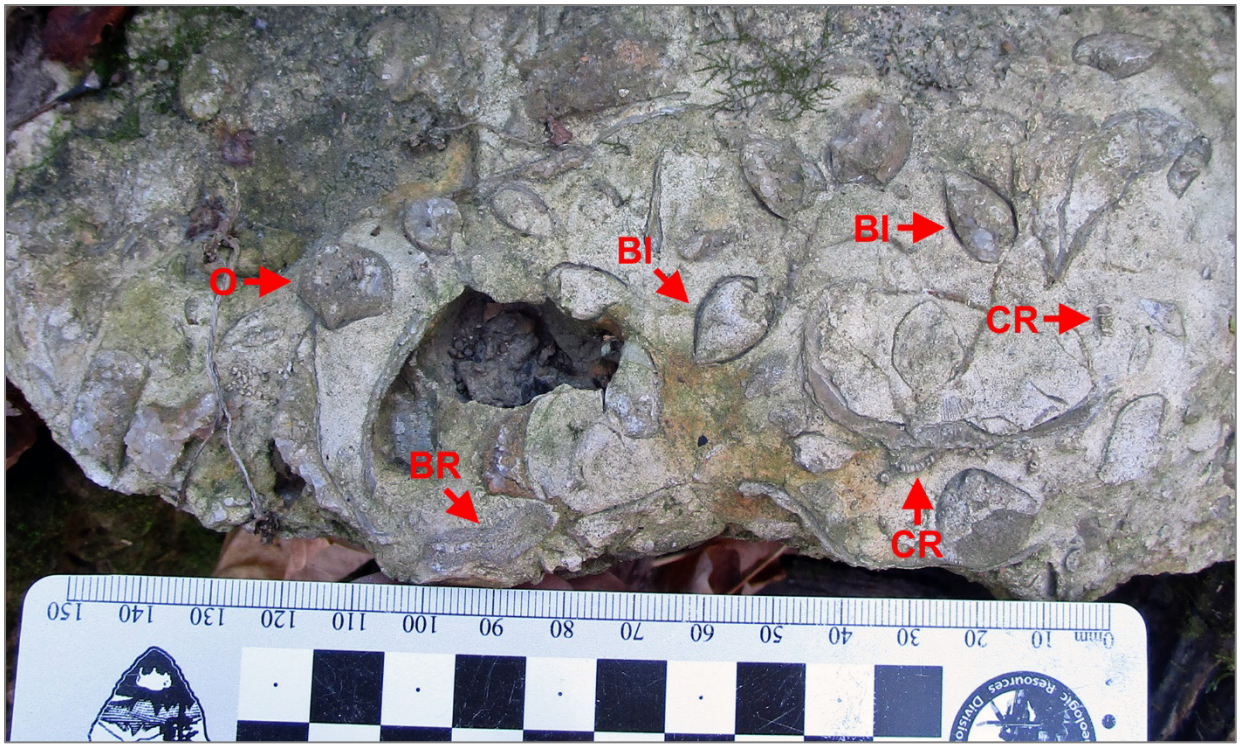


Figure 29. Various fossils. They include: an orthid steinkern ("O"); several bivalve cross-sections (two good examples are marked "BI"); a poorly preserved bryozoan cross-section ("BR"); and strands of crinoid ossicles ("CR"). Note also post-depositional crystals. NPS / JUSTIN TWEET

Phylum Mollusca: Class Bivalvia (clams, oysters, etc.)

Bivalves are familiar aquatic invertebrates today, including clams, oysters, scallops, and others, but were much less abundant and diverse during the Paleozoic. As noted above, most bivalves can be distinguished from most brachiopods by their symmetry (asymmetric single valves, valves symmetric to each other), although there are exceptions. Symmetric, roughly heart-shaped cross-sections are the best evidence of bivalve fossils at EFMO (Figures 29 and 30); there is also at least one instance of a distinctly asymmetric shell with no radiating ribs (Figure 31). These shells are likely examples of cyrtodontids (e.g., *Cyrtodonta*, *Vanuxemia*), "chunky" rounded bivalves that are relatively abundant in the Platteville Formation.



Figure 30. Several shells are visible in cross-section. They include symmetric or nearly symmetric pairs of valves representing bivalves (not all sections are ideally oriented to produce perfect symmetric sections), and in the upper left a planar section through a gastropod shell (inflated U shape). NPS / JUSTIN TWEET

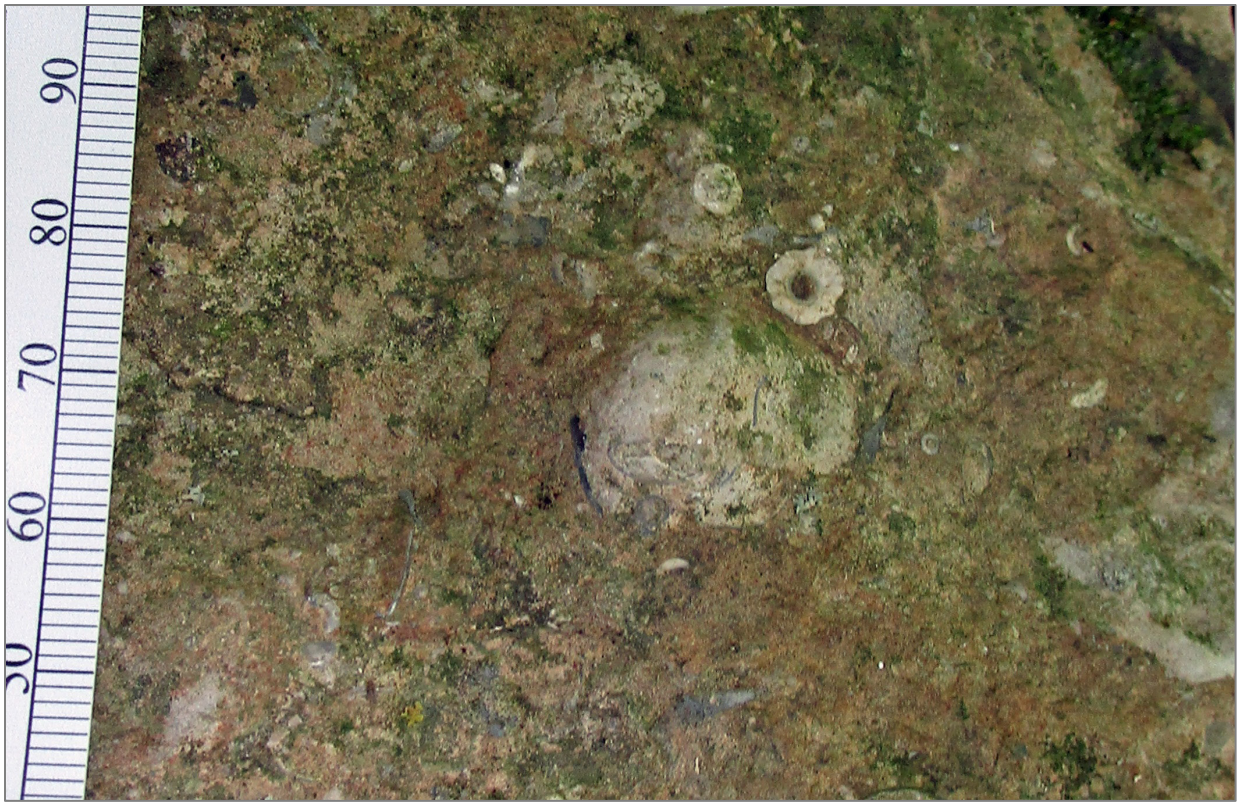


Figure 31. A likely cyrtodontid bivalve. Crinoid columnals are visible adjacent and nearby. NPS / JUSTIN TWEET

Phylum Mollusca: Class Cephalopoda (octopuses, squids, nautiloids, etc.)

There are several subclasses of cephalopods, but only the Nautiloidea are known from the Ordovician. Ordovician nautiloids frequently had elongate straight or gently tapered shells, a shell form known as orthoconic, but others were gently curved (cyrtoconic), loosely coiled (gyroconic), or tightly coiled like the modern chambered nautilus (tarphyconic). All of these shell types are divided into numerous internal chambers by walls called septa; the chambers are connected by an internal passage called a siphuncle. Nautiloids were diverse in the Platteville Formation and varied greatly in size, from finger-sized (or smaller) to several meters long; large nautiloids are frequently only partially preserved, because their diameters were greater than the depth of sediment available to cover them. No large nautiloids were observed at EFMO, but at least three smaller forms were seen: a small orthoconic form (Figure 26), a larger annulated orthocone, perhaps *Anaspyroceras lesueuri* (Figure 32), and a somewhat larger cyrtoconic or gyroconic form (Figure 32). Note that small poorly preserved or incompletely exposed orthocones may be confused with crinoid stems (Figure 33); depending on what is visible, it may not be possible to distinguish between the possibilities. Crinoid columnals are usually more ornate than nautiloid chambers, and finding more than a half-dozen articulated columnals is uncommon in these rocks.



Figure 32. This complex hash includes several noteworthy fossils. Upper left: a few weathered chambers and a partial mold of a cyrtoconic or gyroconic nautiloid (“N”; not enough is present to differentiate). Upper right: two gastropod taxa in cross-section, one with a wide coil (“G”), the other a high-spired *Hormotoma* (“H”). Lower right: the last few chambers of an annulated orthocone, perhaps *Anaspyroceras lesueuri* (“A”). Note also two banana-shaped features near the center that may be nautiloid molds or filled burrows. NPS / JUSTIN TWEET



Figure 33. This fossil is most likely a small weathered orthocone but is also very similar to a partial crinoid stem. NPS / JUSTIN TWEET

Phylum Mollusca: Class Gastropoda (snails)

Gastropod shells are the second-most abundant kind of fossil in the Platteville Formation at EFMO and are also present in the Prairie du Chien Group and the Holocene sediments of Founders Pond. No description was offered for the Holocene material by McGuire Bogen and Hotchkiss (2007), so it will not be discussed further. The Paleozoic shells have a variety of forms based on the angle of coiling. Some are coiled in a flat (planispiral) or nearly flat (pseudoplanispiral) plane, whereas others have stacked whorls, sometimes making cones, in other cases having a steep "snowman"-like appearance. For instance, in Shumard's (1852) description of gastropods from the bluffs of EFMO, two forms are identified: "*Euomphalus*", probably planispiral or pseudoplanispiral, and "*Natica*", likely with a conical profile.

Interestingly, almost all of the gastropod fossils observed in EFMO were cross-sections. This makes it difficult to offer identifications of genera or species, but several general forms can be identified. The gastropod cross-section from the Prairie du Chien Group is only part of a complete cross-section because of poor preservation and damage to the rock (Figure 34). A complete cross-section would show a second similar stack of whorls, in a straight line or shallow angle to the existing set if coiling was approximately planispiral, or at a steeper angle if the shell was cone-shaped (both configurations can produce a half cross-section resembling this specimen, and both are known from the Prairie du Chien Group). The "points" on the corners of the whorls represent ridges.



Figure 34. A partial gastropod cross-section in chert. NPS / JUSTIN TWEET

Five or six kinds of gastropods were distinguished in the Platteville Formation rocks of EFMO:

A low-coiling form with fine ridges was seen on one slab (Figure 25B) and tentatively assigned to *Ophiletina*.

High-spired gastropods with smooth, rounded whorls are apparent both as cross-sections and as exposed fossils (Figures 32, 35, 36), and are the most abundant recognizable gastropod fossils. They are tentatively assigned to *Hormotoma*.

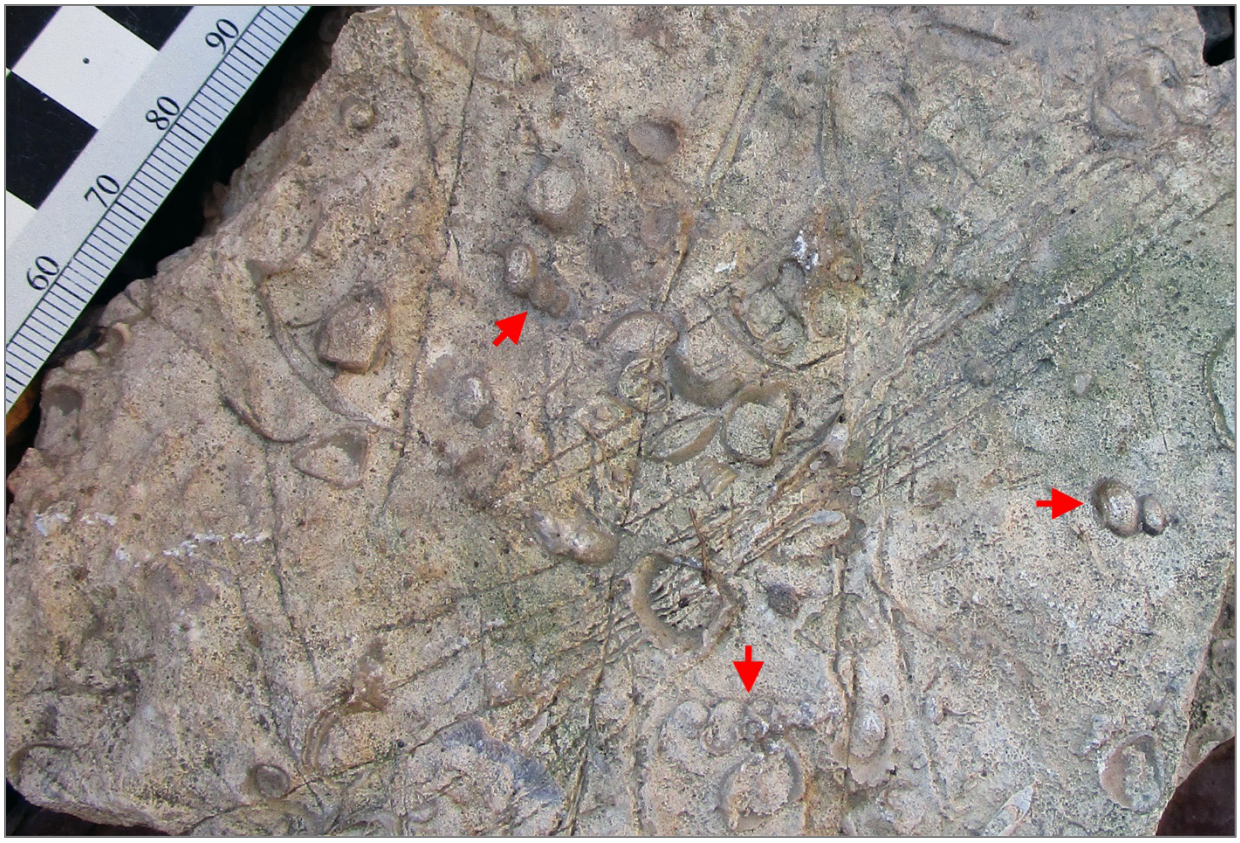


Figure 35. Three examples of *Hormotoma* are indicated by red arrows. NPS / JUSTIN TWEET

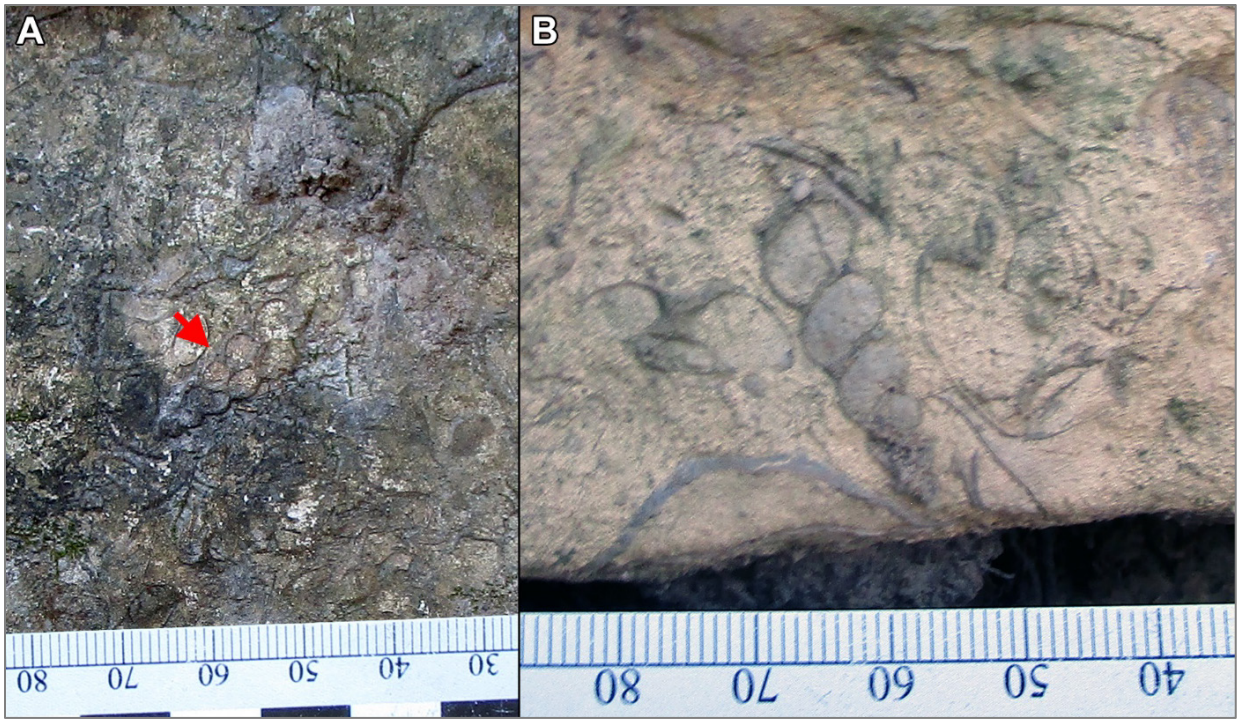


Figure 36. Two views of *Hormotoma* cross-sections. **A.** A section that includes the interior wall. **B.** A section that does not include the interior wall. NPS / JUSTIN TWEET

A single large gastropod with a smooth conical shape is interpreted as *Clathrospira* (Figure 37).



Figure 37. A large *Clathrospira* (outlined in red), partially covered in mud. NPS / JUSTIN TWEET

A cross-section with an extensive spiral represents a planispiral or pseudoplanispiral form (Figure 38), of which there are several candidates. This is not a coiled nautiloid because there are no chambers. Also visible in Figure 38 is what appears to be a small scroll-form gastropod similar to *Subulites*, either crushed in such a way as to break off part of the outer whorl or adjacent to a shell fragment of similar composition.



Figure 38. A cross-section of a small planispiral or nearly planispiral gastropod. Below and to the left is what appears to be a small *Subulites*-like scroll-form gastropod. NPS / JUSTIN TWEET

A distinctive cross-section perpendicular to the whorl represents a bellerophontid, a type of planispiral gastropod or gastropod relative with a tight spiral and a flared aperture (Figure 39). The shape of the whorl sections indicates a fairly squat whorl with triangular ridges.



Figure 39. This cross-section represents a bellerophontid gastropod. NPS / JUSTIN TWEET

There are other cross-sections that cannot be attributed to one of these forms and presumably represent other gastropod taxa, but little can be said about them (Figure 40).

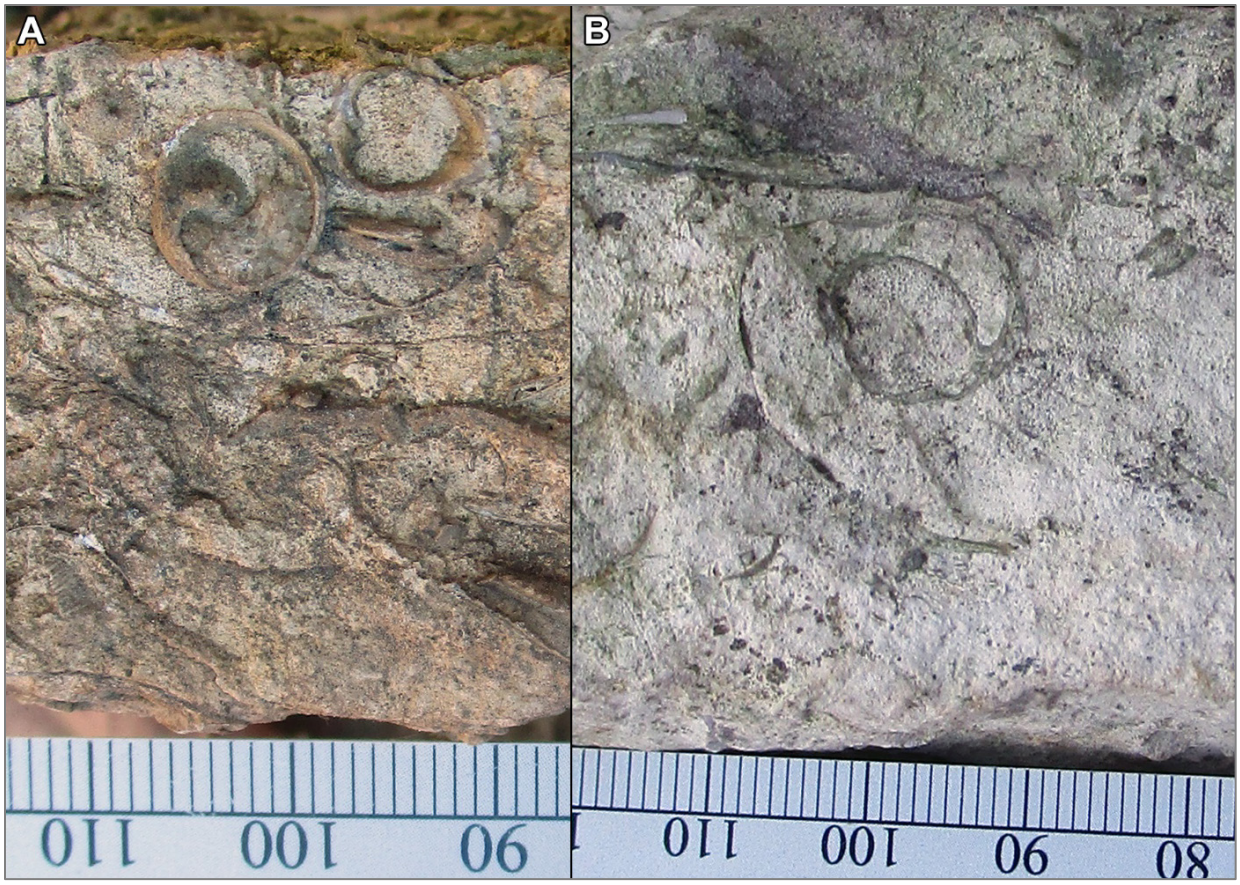


Figure 40. Examples of undetermined gastropod cross-sections. **A.** A section across a whorl (note also the partially exposed bivalve cross-section to its right and the *Hormotoma* in the left center) **B.** A partially crushed section of a low-coiling shell. NPS / JUSTIN TWEET

Phylum Arthropoda (arachnids, crustaceans, insects, etc.)

Arthropods (animals with jointed bodies and exoskeletons) are represented by fossils of two groups at EFMO: trilobites and ostracodes. Both groups differ from most of the others considered here by incorporating phosphate minerals in their hard parts, so their fossils are more resistant to chemical processes that affect carbonates and may look different (trilobite fragments are frequently darker or lighter than other fossils in the same rock). Trilobites are one of the most familiar types of Paleozoic invertebrates. Because trilobites shed their exoskeletons to grow, most trilobite fossils are partial pieces of these shed exoskeletons, particularly the tail region (pygidium) and parts of the head region (the entire head shield is the cephalon; usually parts of the cheeks are missing, leaving what is called a cranidium). The central segments of the trilobite are rarely found intact, and the antennae and limbs are very rarely found at all. Fragments of trilobites may be biological "trash" in Paleozoic rocks, not identifiable except when observed microscopically. Trilobite pygidia were observed in two blocks at EFMO (Figure 41), another block has paired fragments of a larger trilobite, likely genal ("cheek") spines (Figure 42), and a third block has what appears to be a partially weathered body (Figure 43). If the latter is the case, there may be two or three trilobite taxa represented, one a small form with a simple pygidium (perhaps a pterygometopid such as *Calyptaulax* or *Sceptaspis*), and a larger form

with prominent genal spines; the body segments of Figure 43 may belong to the latter or to a third taxon.

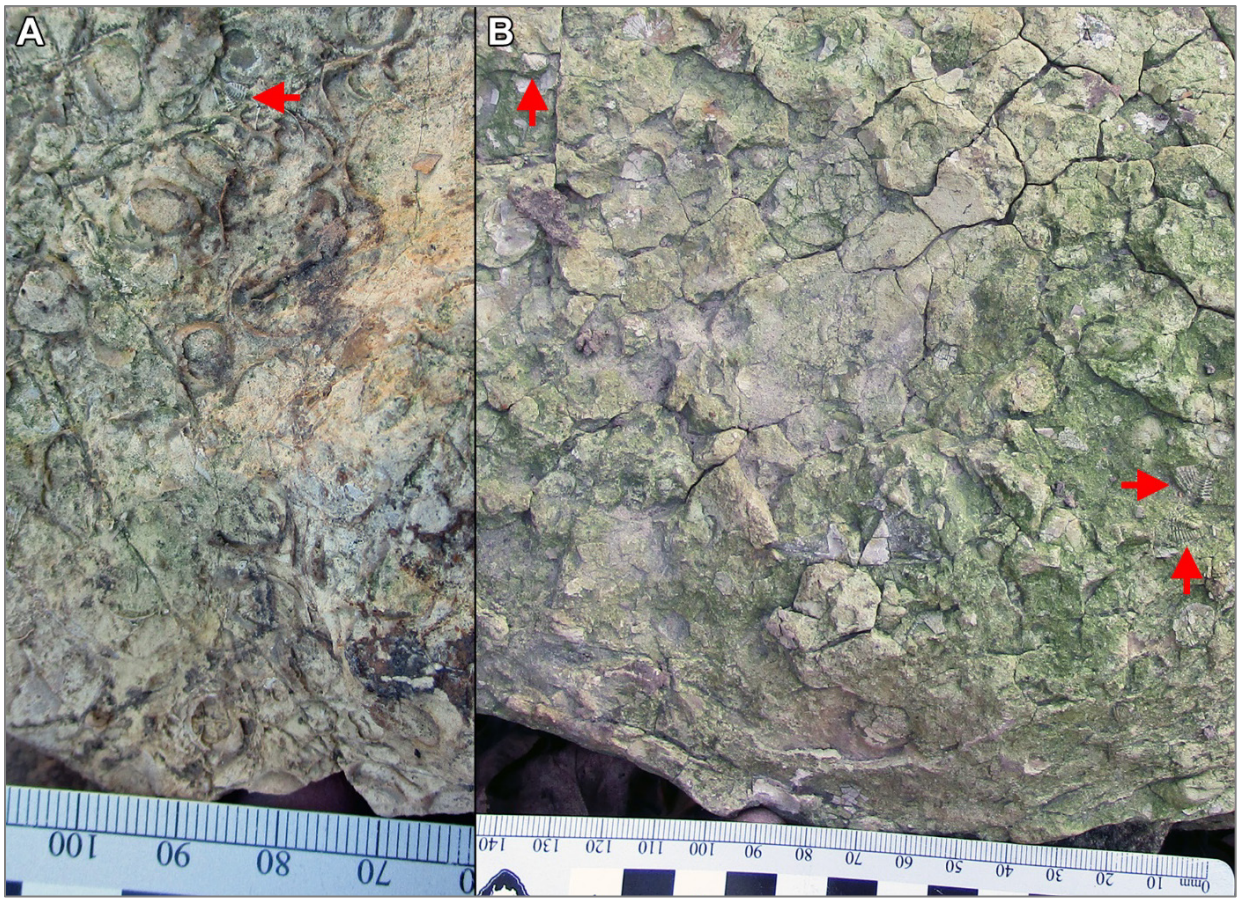


Figure 41. Small trilobite pygidia are indicated by red arrows. NPS / JUSTIN TWEET

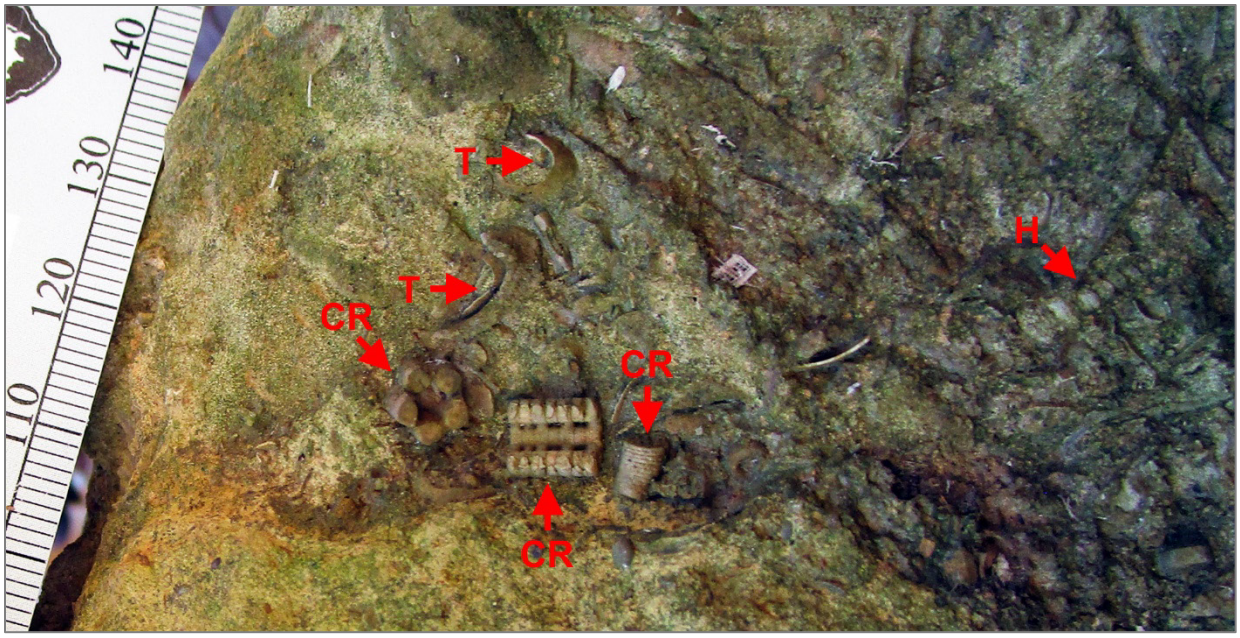


Figure 42. The two strongly curved objects denoted “T” represent trilobite genal spines or similar paired elements. Note also crinoids (“CR”) including a partially dissected crinoid column and associated five-lobed “floral” columnal, and the *Hormotoma* (“H”) on the right. NPS / JUSTIN TWEET

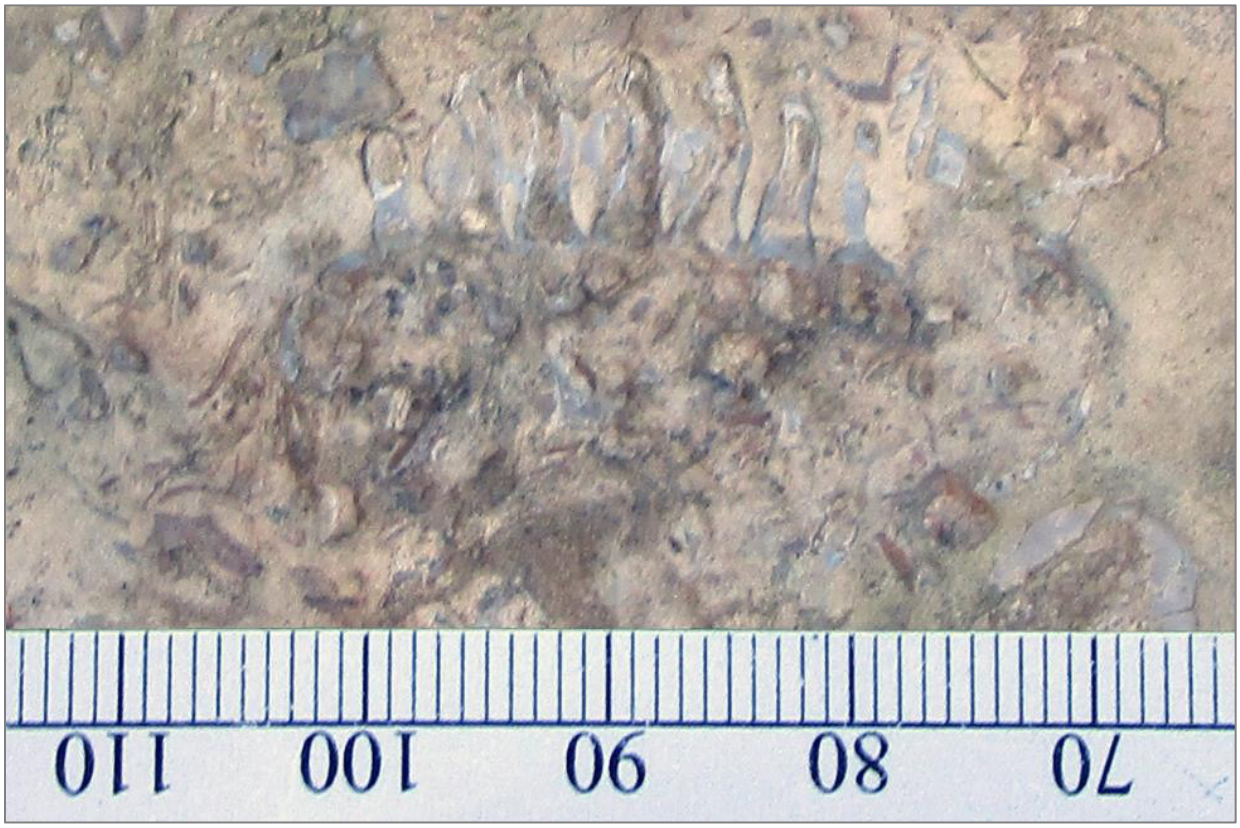


Figure 43. The rib-like features are interpreted as the tops of a heavily weathered series of trilobite thoracic segments. NPS / JUSTIN TWEET

Ostracodes, also known as “seed shrimp”, are bivalved crustaceans, generally microscopic. Unlike trilobites, they continue to flourish today. Most ostracodes are less than 1 mm (0.04 in) long, but the Platteville Formation has examples of the much larger *Eoleperditia*, resembling a bean in size and shape, up to about 1 cm (0.4 in) long (Figures 44 and 45).



Figure 44. The two associated elliptical objects on the right are interpreted as a partially weathered *Eoleperditia* hinged open, with the concave interior surfaces facing the viewer. Note the optical illusion; these are not convex exterior surfaces! NPS / JUSTIN TWEET



Figure 45. Some or all of the four indicated bean-like fossils are likely *Eoleperditia* (some could be small pygidia or cephalons of *Bumastoides* or other illaenid trilobites). NPS / JUSTIN TWEET

Phylum Echinodermata (sea stars, brittle stars, sea lilies, sea urchins, etc.)

Echinoderms include living groups such as asteroids (sea stars), echinoids (sea urchins), and crinoids (sea lilies), and are noted for their radial five-fold symmetry, water vascular system, and exoskeleton of small, mineralized pieces called ossicles. Upon death, an echinoderm's body usually disintegrates into its component ossicles, so complete specimens are rare but fragments are abundant. Crinoids are the only fossil echinoderms definitely known from EFMO to date. If they were complete, they would be composed of a crown made up of a cup-like or globular body (calyx) with a series of long slender arms used for filter feeding, supported on a long stalk or stem leading to a holdfast that attached to the ground or another organism. Apart from a few short strands of small ossicles that may represent portions of arms (Figure 29), the crinoid fossils at EFMO are columnals, the individual segments of the stalk. These are generally ring-like or sprocket-like and a few millimeters across (less than 0.4 in) and are abundant, albeit rarely the most noticeable fossils in a given rock. Although they are abundant, columnals are usually not useful for taxonomy because they are generally similar between species and crowns are often found disassociated from stalks. However, several distinct columnal forms have been observed at EFMO, and better columnal–crown associations may eventually allow some to be attributed to genera or species. Most of the observed columnals are simple short cylindrical segments with a central hole (e.g., cover image and Figure 31). Sprocket-like or gear-like columnals with nodular "teeth" are also fairly abundant (Figures 46 and 47). Some columnals are circular with a thin ridge partway down (Figure 47), most evident in side view (Figure 48); these particularly resemble columnals found attached to *Abludoglyptocrinus* and plausibly represent that

genus. A few show five circular “lobes” rather than a solid rim, giving them a flower-like appearance (Figures 42, 49, and 50). Finally, there is one well-preserved pentagonal columnal (Figure 26).

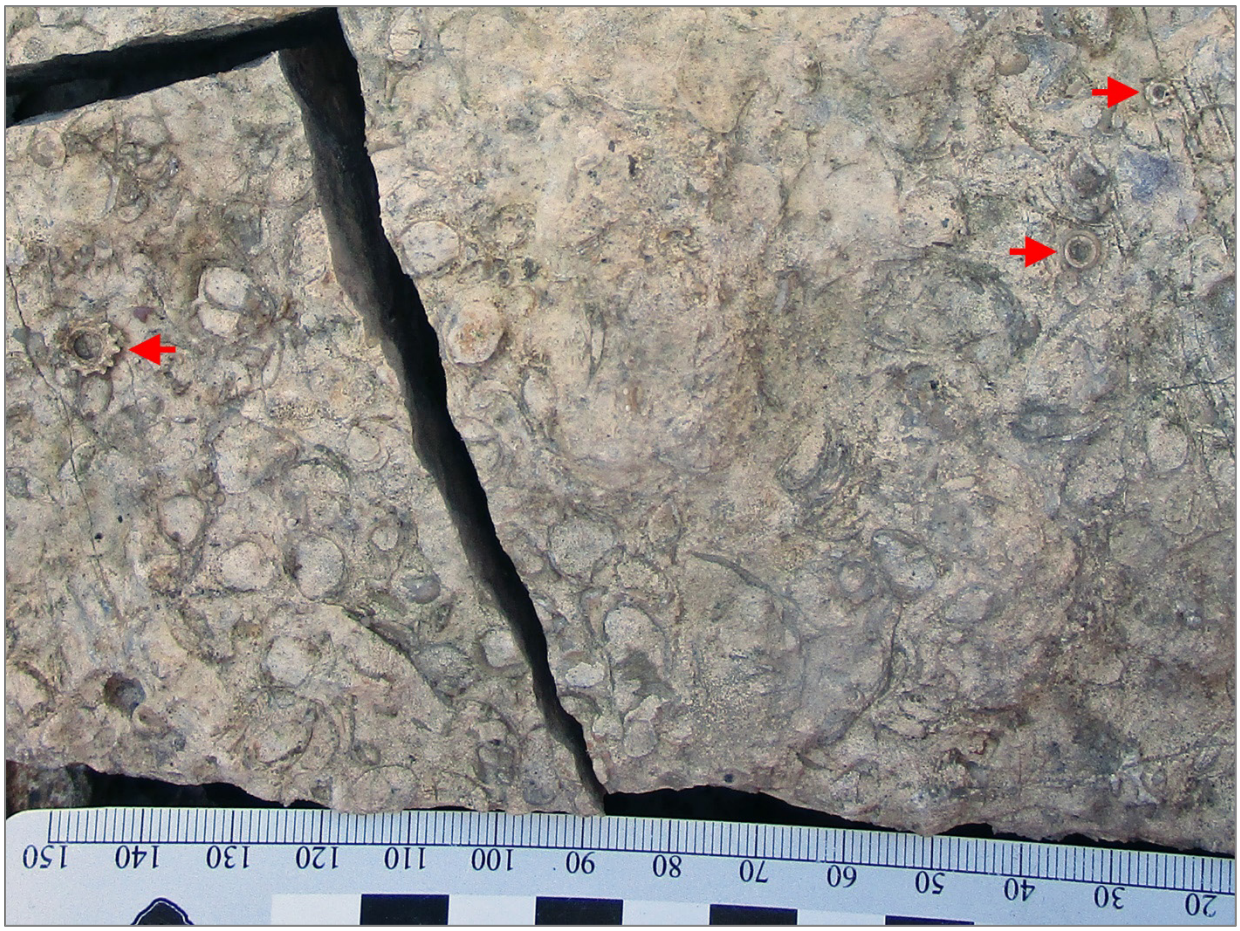


Figure 46. Three columnals are indicated by red arrows: a large “sprocket” on the left, a smaller “sprocket” in the upper right, and a columnal with a “waist” ridge below it. NPS / JUSTIN TWEET

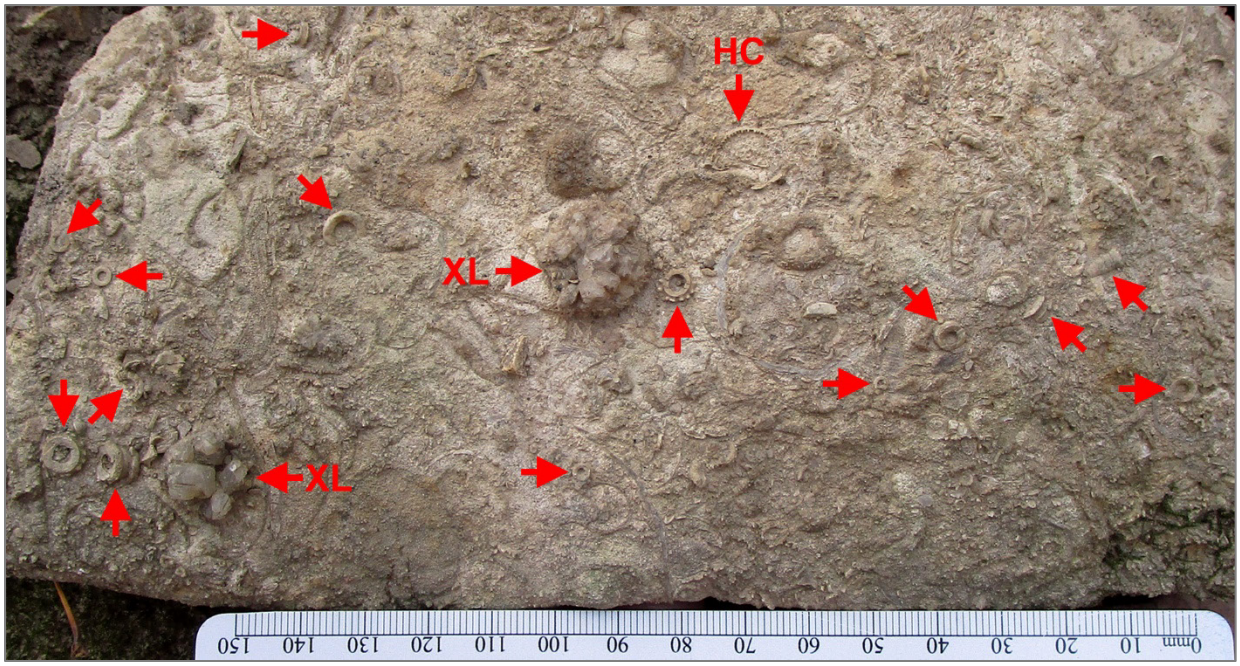


Figure 47. Numerous columnals of multiple forms are visible in this rock, including simple circular, ridged, and sprocket-like. Many are indicated by red arrows. Note also the clusters of post-depositional crystals ("XL") and the rim of a horn coral ("HC"; the "teeth" on the curve somewhat resemble the "sawtooth" anatomy of graptolite colonies, tiny worm-like filter-feeding animals). NPS / JUSTIN TWEET



Figure 48. A short segment of multiple articulated ridged columnals, potentially *Abludoglyptocrinus*. NPS / JUSTIN TWEET

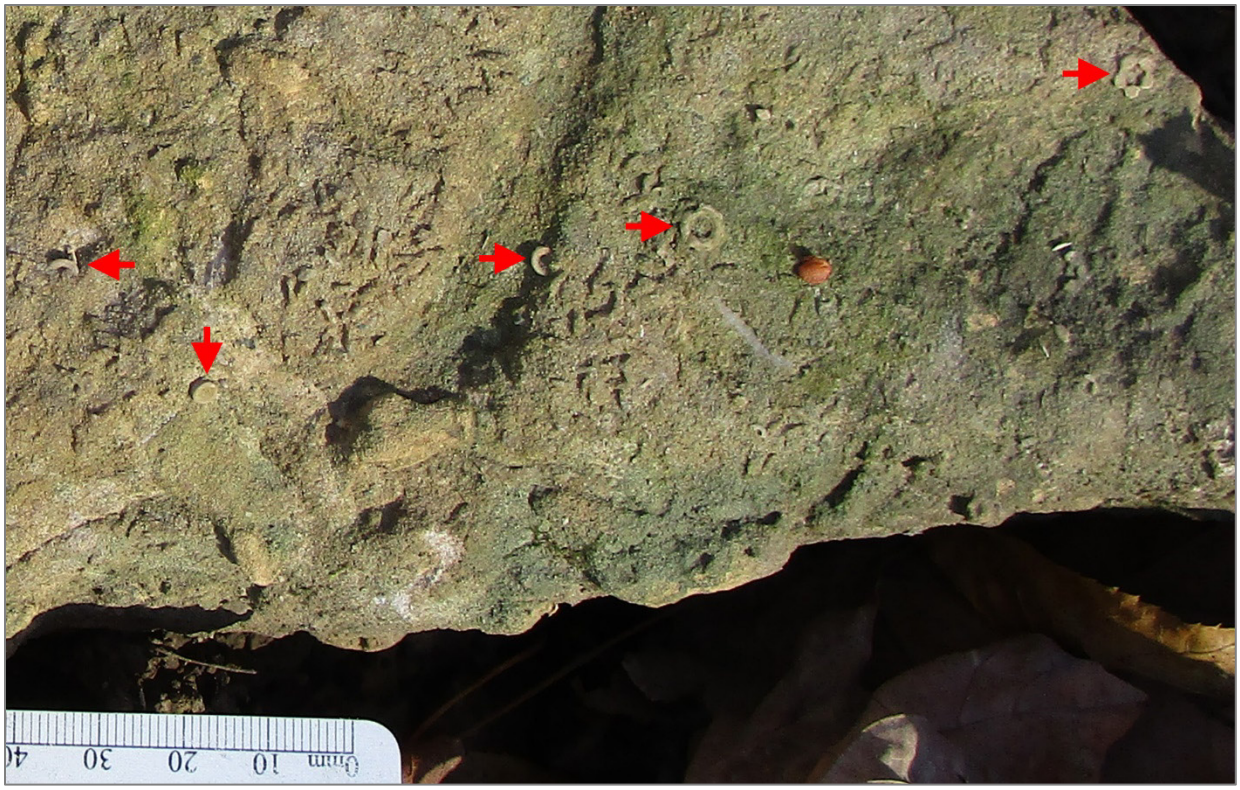


Figure 49. Several columnals are indicated by red arrows, including a five-lobed example in the upper right. NPS / JUSTIN TWEET

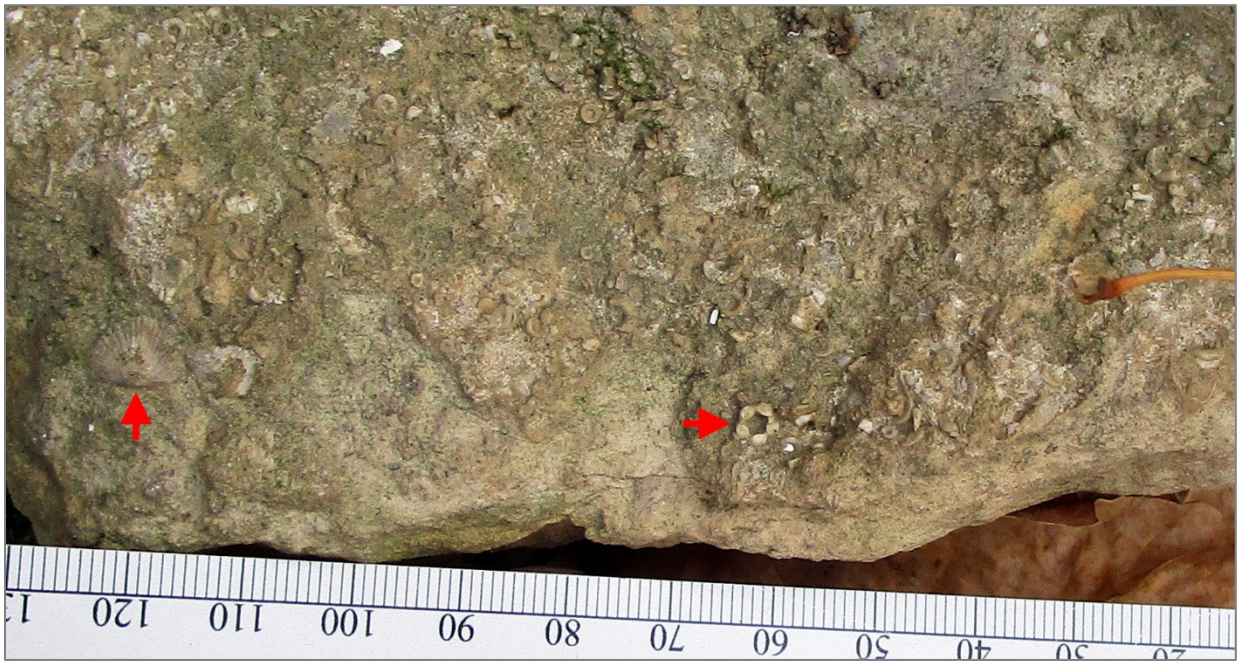


Figure 50. Columnals are scattered across this surface, including a five-lobed example indicated by a red arrow. Note also the small *Hesperorthis* in the lower left, also indicated by a red arrow. NPS / JUSTIN TWEET

Other Invertebrates

One Platteville fossil appears to be a steinkern of a hyolith (Figure 51). Hyoliths are an extinct group of small Paleozoic invertebrates. A typical hyolith had a tapered triangular shell less than 5 cm (2 in) long with a roughly triangular cross-section, a lid-like structure (operculum) covering the wider open end of the shell, and a pair of movable long slim tapered structures (helens) projecting laterally from the opening. Historically, hyoliths were often thought to be mollusks, perhaps gastropods or related to them, but it has been discovered that they had lophophores, which means they were more closely related to brachiopods, which also have lophophores (Moysiuk et al. 2017). There are no identifying features on the EFMO specimen, so it is classified as an undetermined hyolith.



Figure 51. The elongate triangular fossil overlying the right-most strophomenid brachiopod is interpreted as a hyolith steinkern. NPS / JUSTIN TWEET

Inevitably in a situation as seen here with numerous fossils and fossil fragments that are only partially exposed, there are many fossils that are difficult or impossible to identify. As can be seen from the figures above, many rocks are crowded with such fragments. There are also a few that seem to be large enough or distinctive enough that they should be identifiable, but stubbornly defy identification. For example, an unusual ringed structure was observed in Prairie du Chien Group rocks (Figure 52). At first Tweet interpreted it as the central whorls of a planispiral or nearly planispiral gastropod, but enough of the structure seems to be present to rule out a spiral; instead, the feature appears to show a rounded raised ring within a larger dish-like structure. Some other possibilities include a receptaculitid (it is somewhat similar to *Ischadites*, albeit with two ridges instead of a more discoidal shape, perhaps suggesting some kind of collapse); an impression of the face of a nautiloid chamber showing an unusual siphuncle; or an echinoderm fossil, perhaps a holdfast for a crinoid or other stalked echinoderm or the socket of an echinoid's spine. It could also

be a mold of a crinoid columnal, although crinoids of this size have not been reported from the Prairie du Chien Group.



Figure 52. An enigmatic ringed fossil observed in Prairie du Chien Group rocks. NPS / JUSTIN TWEET

Another unusual fossil, this time in the Platteville Formation, somewhat resembles an orthoconic nautiloid with a step-like fold (Figure 53). The apparent kinking may be exaggerated by differential removal of the stone around it, but the "chambers" are definitely not parallel to each other. Some gyroconic nautiloids (e.g., *Centrocyrtoceras*) show some of these features, but not all (unless pathological or unusually affected by the processes of fossilization). An impression of the thoracic segments of a large trilobite (e.g., *Isotelus*) that has been contorted could also conceivably show some of these features.

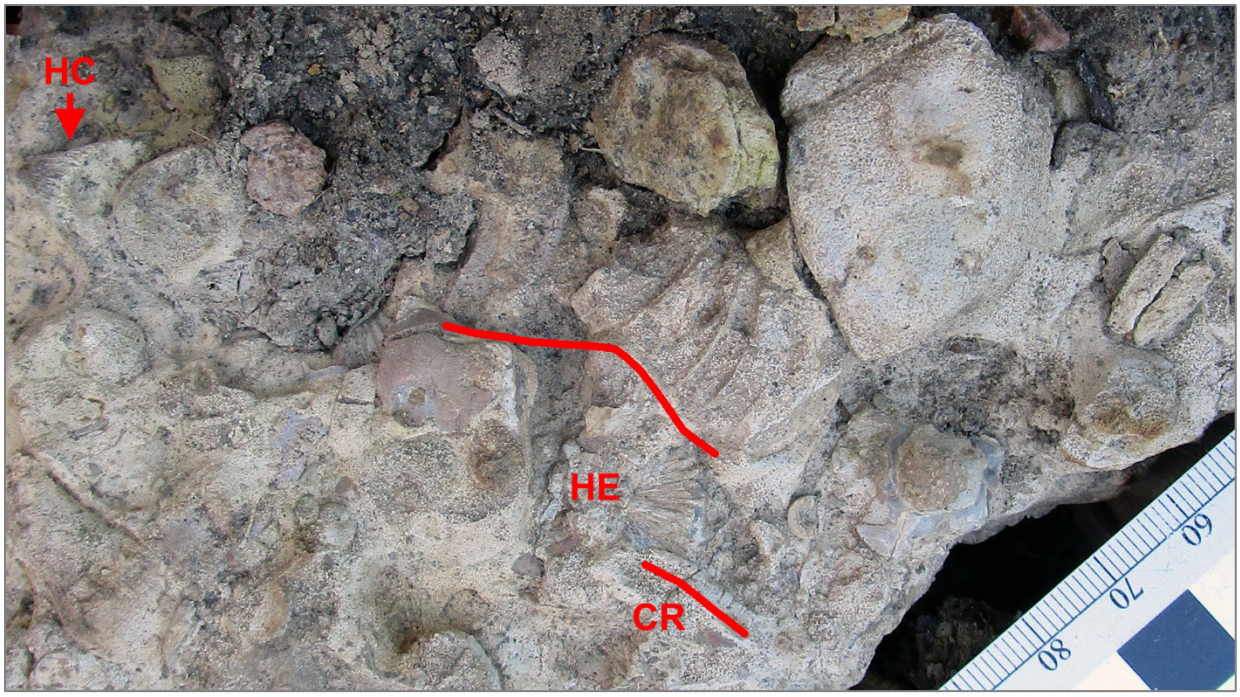


Figure 53. The center of the photo is dominated by what resembles an orthoconic nautiloid with a step-like fold (lower margin paralleled by red line). Several more identifiable fossils are also visible, including a horn coral (“HC”), a *Hesperorthis* shell (“HE”), and a strand of crinoid ossicles probably from an arm (“CR”; lower margin paralleled by red line). NPS / JUSTIN TWEET

Ichnofossils

The Prairie du Chien Group is noted for stromatolitic intervals. Stromatolites are fossilized layered microbial structures and include aspects of trace fossils, sedimentary structures, and body fossils (occasional microscopic evidence of microbial bodies and filaments). They form as a result of cyclic microbial growth and sedimentation. In lateral or cross-sectional view, they often look like fine wavy or arched laminations, stacked in distinct columns or growing in large masses. In a planar view (Figure 12), the individual columns or masses may be evident as domes (upper surface of interval) or depressions (basal surface), sometimes with concentric features due to individual layers spalling off. In the Prairie du Chien Group as a whole, stromatolitic intervals may form zones of relative weakness (anecdotal observation by the lead author), and if not protected by more cohesive rock above and below will disproportionally erode, leading to shed stromatolitic blocks. There is some risk of collection because well-preserved stromatolitic blocks can make striking landscape stone; interest would primarily be aesthetic because stromatolites are unfamiliar to most people. At EFMO, McKay (1993) observed stromatolites in the Oneota Formation at Hanging Rock, and Tweet observed a shed block likely derived from the Prairie du Chien Group. They are probably present throughout the monument where outcrops are present but may be difficult to recognize due to extensive weathering and growth of mosses and other organisms.

Invertebrate burrows and trails are also present in several formations, including the Jordan Formation (Figure 9), Prairie du Chien Group (Figures 54 and 55), and Platteville Formation (Figure 56). They

may be present in the St. Peter Sandstone as well, but the extensive surficial weathering makes it difficult to identify such fossils.



Figure 54. A heavily burrowed Prairie du Chien Group block. NPS / JUSTIN TWEET



Figure 55. A Prairie du Chien Group block with large trace fossils. NPS / JUSTIN TWEET

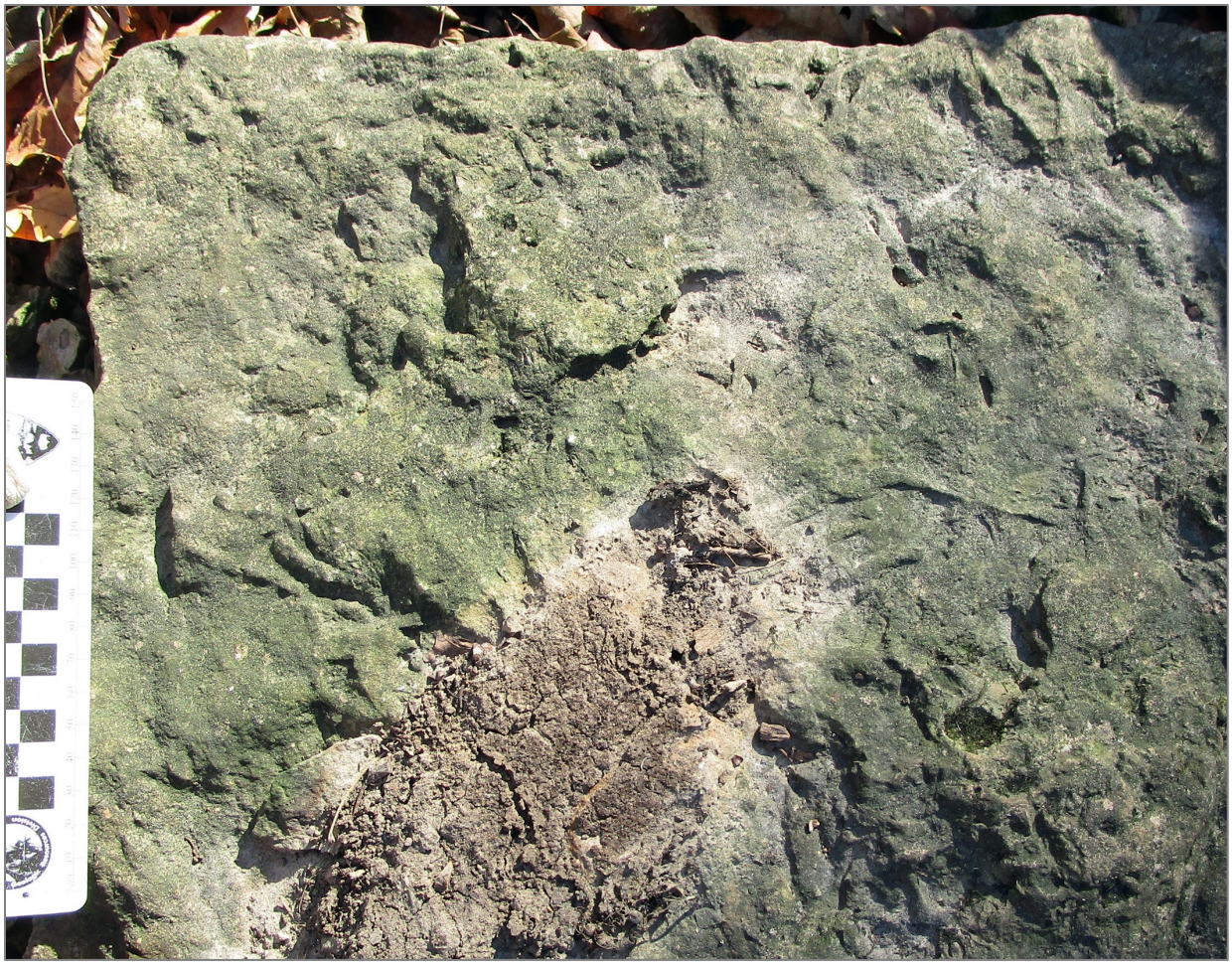


Figure 56. A block of Platteville Formation rock with various invertebrate trace fossils. NPS / JUSTIN TWEET

Other Fossils

Diatoms, a type of aquatic “algae” that have cell walls of silica, as well as unspecified “algae” have been recovered from the Founders Pond core (McGuire Bogen and Hotchkiss 2007).

Fossil Localities

Paleontological Localities Within EFMO

The bedrock fossils of EFMO are marine invertebrate body fossils and trace fossils and microbial structures. These kinds of fossils are generally not localized the way that terrestrial vertebrate and plant fossils often are. Instead, a bed that is fossiliferous in one area is often fossiliferous to a similar extent over a wider area. This reflects origination in widespread favorable marine environments. Therefore, rather than discrete localities, it can be more practical to think of these fossils in terms of productive areas, dictated by where productive intervals are at or near the surface. This is particularly true of the Platteville Formation. The Decorah and Dunleith Formations are not known to be exposed in EFMO, but if outcrops are located or produced by erosion, construction, or other means of exposing bedrock, their fossil potential is at least similar to the Platteville Formation, potentially greater. The Jordan Formation can be considered sporadically productive throughout, with fossils limited largely to small vertical invertebrate burrows. The St. Peter Sandstone is not known to be fossiliferous in EFMO, but as a paleontological unit it can be considered similar to the Jordan Formation but less productive. The Prairie du Chien Group is also poorly productive. Some intervals are stromatolitic or have invertebrate burrows, and some shell cross-sections have been observed in chert, but apart from these, fossils are scarce. Furthermore, although there are good outcrops of the Prairie du Chien Group in EFMO, they are almost entirely vertical bluff faces, meaning that practical access is limited (although this is beneficial from a resource protection standpoint). Further details on localities and monitoring recommendations are available to EFMO staff and qualified researchers.

Paleontological Localities Near EFMO

EFMO is within a greater area of Paleozoic bedrock exposures; as noted in the Introduction, many Paleozoic geologic units are named for exposures in the area. Practically any exposure of the Platteville Formation and higher units will yield fossils. Fossils of the Galena Group, including the Decorah and Dunleith Formations, will be similar in many ways to Platteville Formation fossils.

Cultural Resource Connections

There are many ways for paleontological resources to have connections to cultural resources. Examples of paleontological resources in cultural contexts include, but are not limited to: fossils used by people for various purposes, such as petrified wood used for tools, spear points, and other artifacts, or fossil shells picked up as charms or simply because they looked interesting; associations of prehistoric humans with paleontological resources, such as kill sites of mammoths, prehistoric bison, and other extinct animals; incorporation of fossils into cultural records, such as fossils in American Indian lore, "tall tales" of mountain men, and emigrant journals; and fossils in building stone. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts. At EFMO, there are examples of fossils at a site identified as archeological. More tangentially, the Holocene material in the Founders Pond core is an important resource for reconstructing the environment during the time the mounds were being built.

Fossils are present in chert at a site identified as a Native American chert quarry in the form of shell cross-sections (Figures 34 and 57). Chert fragments were not formally studied to determine whether they constitute debitage, but the possibility exists, and observation of local chert tools may reveal similar fossil cross-sections. A prehistoric clamshell midden has been found in the Hanging Rock area (McKay 1993); such material is not generally considered paleontological resources, but there is potential for older sites in the monument. There is also an interesting but to date unsubstantiated potential connection with the effigy mounds themselves: Hanger (2008), in a conference abstract, suggested that linear effigy mounds are representations of orthoconic nautiloids. The idea is not impossible, but a linear shape is simple and therefore difficult to firmly attribute to something without other data.

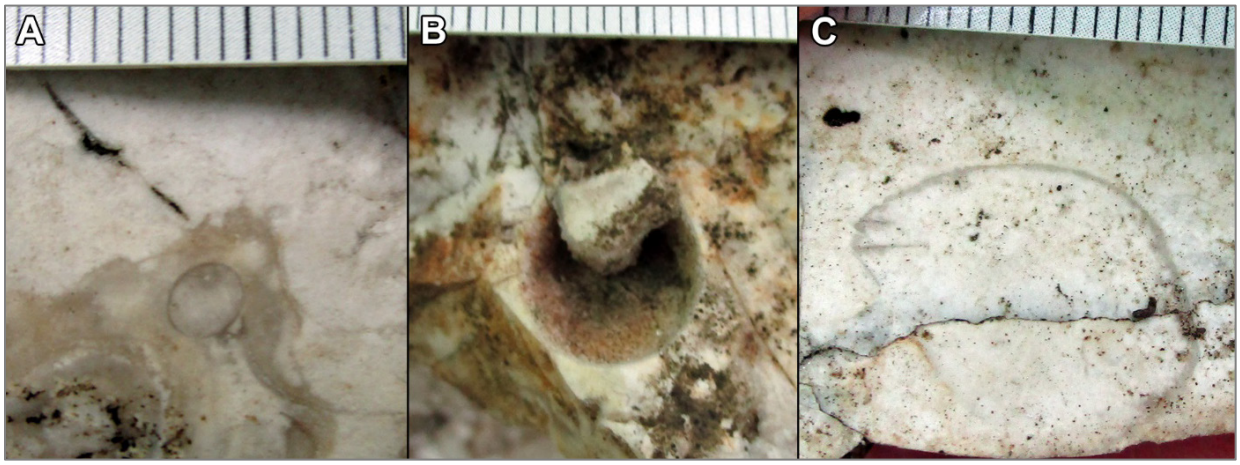


Figure 57. Several fossil cross-sections and molds in chert. NPS / JUSTIN TWEET

Museum Collections and Paleontological Archives

Museum Collections and Curation

EFMO has a substantial collection of fossils that derive from Ellison Orr's work as well as a small number of fossils in the interpretation and education collection that are not included in catalogued collections (see "Interpretation" below).

EFMO Collections

According to the 2023 EFMO collections management report, 3,640 specimens are cataloged as paleontological, 600 of which are in backlog. However, during his November 2023 visit, Tweet received a file corresponding to 644 catalog numbers. The discrepancy is due to individual objects versus catalog numbers, as noted in Hunt et al. (2008) ("The park collections contain a large number of paleontological specimens, 635 (perhaps more than 3,000 individual specimens; K. Byrne, HFC Curator, pers. comm. January 2008).").

Whatever the exact numbers, EFMO has a large number of paleontological specimens in its collections. In fact, according to 2023 collections management reports, it has the fifth-most paleontological specimens in the Midwest Region, behind only the noted paleontological parks Agate Fossil Beds National Monument, Badlands National Park, Theodore Roosevelt National Park, and Wind Cave National Park, and just ahead of another notable paleontological park, Scotts Bluff National Monument. Only a tiny percentage can be attributed to EFMO itself, though, including two specimens collected by Robert Kile during the mid-20th century. The rest, occupying 18 drawers in three cabinets per a brief assessment by Tweet in November 2023, are from Ellison Orr's paleontological collection. A few "paleontological" specimens are actually other types of geological objects, but this number is probably smaller than 50. Based on the sheer number of fossils, paleontology appears to have been a subject of greater interest to Orr than he is usually credited with; one does not collect approximately 3,600 fossils by accident or for no reason. His collection is substantial enough to have made an excellent teaching or reference collection for a moderately sized college of his era. His interest in geology is known from a few publications (e.g., Orr 1888, 1907) and an acknowledgment in Calvin (1895). Intriguingly, he corresponded with the maverick Minnesota-based geologist and paleontologist Frederick William Sardeson, as mentioned in Weiss (2000). EFMO's archives include several letters exchanged between the two, primarily in 1927–1928, with one letter from February 19, 1934, showing that Sardeson had visited outcrops in the area with Orr in the intervening years. In addition, specimen 489 in the Luther College portion of Orr's collection (see below), a trilobite from Iron Hill, is identified as having been collected by Sardeson. Orr and Sardeson had a mutual interest in locating bentonite horizons in the local Ordovician rocks, per the correspondence.

The collection is overwhelmingly made up of Paleozoic marine invertebrate fossils from northeastern Iowa, particularly the Decorah Formation and overlying Galena Group, but some older Ordovician and Cambrian fossils and some younger Devonian and Carboniferous specimens as well. A full range of fossil groups is included, including relative rarities such as the enigmatic *Scenella* (perhaps a limpet-like mollusk or a float of a jellyfish-like animal) (Figure 58). There are also specimens from

farther afield, such as Mazon Creek concretions (Pennsylvanian of Illinois), Jurassic and Cretaceous marine fossils and Cretaceous plants from the Black Hills, shark teeth, and Quaternary loess snails. Among these are cycadeoids from southeast of Minnekahta, South Dakota (Minnekahta is notable as the location of the former Fossil Cycad National Monument, a famous cycadeoid site, so Orr's cycadeoids are from near but not within the former monument), titanothere bones from what is now Badlands National Park (Figure 59), and fossil wood from "Petrified Forest, Arizona".



Figure 58. A rare fossil, *Scenella radialis*, in the Orr collection at EFMO. The identification as a brachiopod is inaccurate; *Scenella* is now known to be a mollusk or possibly a cnidarian float. Locality information has been redacted. NPS / JUSTIN TWEET



Figure 59. Titanothere material from what is now BADL in the Orr collection. NPS / JUSTIN TWEET

The history of the Orr collection at EFMO is complex, beginning in the 1940s and involving two other institutions. In the early 1940s, Orr donated part of his fossil collection to the Waukon high school and part of it to Luther College (Engebritson 1944). The high school donated it to EFMO in 1958; EFMO in turn did not have the facilities or expertise to curate the material, and eventually placed most of it in the University of Iowa (Iowa City, Iowa; SUI numbers) on long-term loan. In 2001, the university returned this part of the collection, and most of it was given EFMO numbers at this time (S. Oberreuter, pers. comm., 6 September 2024). During the time the material was at the University of Iowa, echinoderm paleontologist James Brower included some of the specimens in his publications and mentioned Orr as collector (Brower and Strimple 1983; Brower 1992a, 1992b, 1994, 1995a, 1995b, 1999, 2013). Among the Orr specimens referenced by Brower is SUI 47559, the paratype of *Cremacrinus gerki* Brower and Strimple (1983) from a non-EFMO locality. It is possible that other specimens cited by Brower are Orr specimens, but this was not directly noted in the publications. The university has retained the published specimens from the long-term loan (Tiffany Adrain, University of Iowa Paleontology Repository collections manager, pers. comm., 12 April 2024).

The Orr fossil collection is an excellent reference collection of the fossils of northeastern Iowa. Admittedly, apart from its origin with Ellison Orr, much of the collection has only a tenuous connection to EFMO, so there is a question of whether EFMO is the ideal repository for the material. (In fact, additional fossils collected by Orr are held by at least one other repository; see below.) The collection as it exists at EFMO has some deficiencies. Most pressingly, although they have been assigned EFMO numbers, the numbers have not been transferred to the specimens (and numbers were never put on many specimens in the first place), so if they were separated from their paper

labels or labeled plastic bags it would be difficult to reassociate them. The plastic bags holding specimens in cardboard trays (Figure 60) are frequently just barely large enough for the trays, so removing and replacing specimens inevitably results in damaged bags and trays. Specimens are also somewhat crowded (Figure 60). On the data side, there are some errors in the catalog and cards, including typos and misidentifications; for example, the Badlands titanothere material has been misidentified as from titanosaurs, a type of dinosaur. The collection would benefit from the attention of someone with paleontological training, but at least a few weeks would be required to address both the physical and data issues. Orr's organization of his fossils is somewhat mysterious as well, with an idiosyncratic numbering system used for both this part of the collection and the Luther College part.



Figure 60. A typical drawer in the Orr collection at EFMO, showing the use of tight plastic bags and some crowding of specimens. NPS / JUSTIN TWEET

Should a more monument-focused collection of specimens be desired, it would be a trivial task to obtain a few representative fossil-bearing stones. However, given the size and quality of the Orr collection, there is little need for this.

Collections in Other Repositories

The Founders Pond core was processed and archived at LacCore, part of the University of Minnesota (McGuire Bogen and Hotchkiss 2007). LacCore is now part of the Continental Scientific Drilling Facility.

The Waukon High School/University of Iowa/EFMO component is not the entirety of the fossils collected by Orr. As alluded to above, in the fall of 1943, Orr donated part of his collection to Luther College (Decorah, Iowa). This was composed of 301 items (Engebritson 1944), including approximately 275 fossils among other geologic materials (Luther College records provided by Laura Peterson, Luther College professor of environmental studies, pers. comm., 2 April 2024). Per the records, the composition of this collection is similar to the collection at EFMO, being primarily Paleozoic fossils from northeastern Iowa with a smattering of fossils from other locations (including Texas, the Mazon Creek beds of Illinois, and the Badlands of South Dakota). The Luther College records may be useful if the EFMO collections are restudied. Finally, the Office of the State Archaeologist of Iowa has 12 catalog numbers containing 26 or fewer fossils (one lot is mixed fossils and non-fossils) in the Charles Reuben Keyes collection; Orr worked with Keyes and may have uncovered some of them or given them to him (Office of the State Archaeologist records provided by Caroline Parris, Office of the State Archaeologist Research Collections Director, pers. comm., 15 May 2024). These specimens appear to represent fossils collected during archeological work, for example found among cultural artifacts or encountered adventitiously during excavations, and as such are distinct from Orr's paleontological collection. (Note that Charles Reuben Keyes is not to be confused with the Iowa-based geologist Charles Rollin Keyes, an associate of Sardeson and another of Orr's correspondents.)

Archives

NPS Paleontology Archives

All data, references, images, maps, and other information used in the development of this report are maintained in the NPS Paleontology Archives and Library. These records consist of both park-specific and service-wide information pertaining to paleontological resources documented throughout the NPS. If any resources are needed by NPS staff at EFMO, or additional questions arise regarding paleontological resources, contact the NPS Paleontology Program at paleontology@nps.gov. Park staff are also encouraged to communicate new discoveries to the NPS Paleontology Program, not only when support is desired, but in general, so that this information can be incorporated into the archives. A description of the Archives and Library can be found in Santucci et al. (2018).

E&R Files

E&R files (from "Examination and Report on Referred Fossils") are unpublished internal USGS documents. For more than a century, USGS paleontologists identified and prepared informal reports on fossils sent to the survey by other geologists, for example to establish the relative age of a formation or to help correlate beds. The system was eventually formalized as a two-part process including a form sent by the transmitting geologist and a reply by the survey geologist. Sometimes the fossil identifications were incorporated into publications, but in many cases this information is unpublished. These E&R files include documentation of numerous fossil localities within current

NPS areas, usually predating the establishment of the NPS unit in question and frequently unpublished or previously unrecognized. Extensive access to the original files was granted to the NPS by the USGS beginning in 2014 (Santucci et al. 2014). No E&R files are currently known for within or near EFMO.

Park Paleontological Research

Current and Recent Research

Apart from this project, under EFMO-2023-SCI-0002 for 2023–2024, there are no records of permits for projects at EFMO that were either paleontological in focus, or a geological project with paleontological significance.

Paleontological Research Permits

See the National Park Service Natural Resource Management Reference Manual DO-77 section on Paleontological Resource Management, subsection on Scientific Research and Collection (https://irma.nps.gov/DataStore/Reference/Profile/572379). NPS Management Policies 2006, section 4.8.2.1 on Paleontological Resources, states that

> *The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit.*

Any collection of paleontological resources from an NPS area must be made under an approved research and collecting permit. The NPS maintains an online Research Permit and Reporting System (RPRS) database for researchers to submit applications for research in NPS areas. Applications are reviewed at the park level and either approved or rejected. Current and past paleontological research and collecting permits and the associated Investigator's Annual Reports (IARs) are available on the RPRS website (https://irma.nps.gov/RPRS/). Additional information on NPS law and policy can be found in Appendix C.

Interpretation

As noted in the "Museum Collections and Curation" section above, EFMO has a handful of fossil specimens available for hands-on interpretation. On Tweet's visit in November 2023, there were seven local fossils at a touch table: a horn coral, a colonial rugose coral, a honeycomb-type tabulate coral, brachiopods in a small rock, a partial crinoid stem, a crinoid crown, and a receptaculitid (Figure 61). These specimens lack provenance information and therefore have not been catalogued. Some of them would not be found in EFMO's bedrock; the colonial rugose coral and tabulate are from younger Paleozoic rocks, for example. The receptaculitid is also relatively unlikely due to the very limited presence of the Dunleith Formation. The fossils are all appropriate for the region, though.



Figure 61. The touch-table fossils available in the visitor center, November 2023. From left: receptaculitid; weathered horn coral; brachiopods in rock (upper row); crinoid stem in rock (lower row); tabulate coral (upper row); crinoid crown (upper row); colonial rugose coral (lower row). NPS / JUSTIN TWEET

Information from this inventory report can be used directly or adapted for interpretive material, including handouts and pamphlets, online content, and scripts for oral presentations (in the auditorium or on guided hikes, for example). Additional material can be created as necessary, for example if certain diagrams would be useful. Staff members who want to gain greater familiarity with local fossils have an excellent resource on-site in the Orr collection.

Current Long Range Interpretive Plan

An updated Long Range Interpretive Plan was prepared for EFMO in 2019 but does not include paleontology or geology.

Recommended Interpretive Themes

I. General Paleontological Information

All of the following interpretation topics include a section instructing visitors how to be paleontologically aware while in EFMO. The ranger will provide the visitor with advice on why fossils are important, how paleontologists look for fossils, what to do if fossils are found, and reminders to be aware that fossils exist and should be respected within EFMO boundaries.

- Fossils are non-renewable resources that possess scientific and educational information and provide insight into what Earth was like thousands and even hundreds of millions of years ago.
- When paleontologists survey for paleontological resources, the most important tool for planning is a geologic map. Paleontological resources are more common in certain geologic units, so knowing where those units are exposed is important for a successful search. Other tools that a paleontologist takes into the field include a field notebook for recording data and observations, small picks and brushes, consolidants to stabilize fossils, GPS, camera, topographic maps, and appropriate First Aid and safety equipment. It might be helpful to provide examples of these items for visitors when giving an interpretive talk.
- If fossils are found in EFMO by a visitor, the visitor should photograph it and notify a ranger of where the resource was found, but most importantly, they should leave the fossil where they found it. It is extremely important for scientific and resource management purposes for locational information to be preserved. Visitors should be informed that NPS fossils are protected by law.

II. Fossils of EFMO

- An educational program could be developed for the public on what types of fossils are present in EFMO and what they tell scientists about Earth's dynamic history. The goal of this program is to increase visitors' understanding of local geology and paleontology. Therefore, information regarding fossils from the vicinity of EFMO can be included.

III. Caves and Fossil Resources

- Paleontological resources are not known from the small cave and rock shelter features at EFMO at present, but there is some potential, including from Quaternary organisms (either arriving via natural means or with some sort of human transport and association) and as bedrock fossils exposed in cave walls. See Santucci et al. (2001) for additional discussion of paleontological resources in cave settings.

IV. Further Interpretation Themes

EFMO should be sure to promote their paleontological resources and provide additional opportunities or programs for visitors to learn about fossils on National Fossil Day, celebrated annually on Wednesday of the second full week in October (National Earth Science Week). For more information on this event visit: https://www.nps.gov/subjects/fossilday/index.htm. The NPS coordinates the National Fossil Day partnership and hosts fossil-focused events across the country. Conducting one or more paleontology-focused activities on this day would be a perfect opportunity

to not only increase public awareness about paleontological resources in EFMO, but also to connect with other parks and museums that are also participating in this national event. The NPS Geologic Resources Division can assist with planning for National Fossil Day activities and provide Junior Paleontologist Program supplies including activity booklets, badges, posters and other fossil-related educational resources (https://www.nps.gov/subjects/fossils/junior-paleontologist.htm).

Paleontological Resource Management and Protection

National Park Service Policy

Paleontological resources are non-renewable remains of past life preserved in a geologic context. At present, there are 431 official units of the National Park System, plus national rivers, national trails, and affiliated units that are not included in the official number. Of these, 286 are known to have some form of paleontological resources, and paleontological resources are mentioned in the enabling legislation of 18 units. Fossils possess scientific and educational values and are of great interest to the public; therefore, it is exceedingly important that appropriate management attention be placed on protecting, monitoring, collecting, and curating these non-renewable paleontological specimens from federal lands. In March 2009, the Paleontological Resources Preservation Act (PRPA) was signed into law as part of the Omnibus Public Land Management Act of 2009. The new paleontology-focused legislation includes provisions related to inventory, monitoring, public education, research and collecting permits, curation, and criminal/civil prosecution associated with fossils from designated Department of Interior (DOI) lands. More information on laws, policies, and authorities governing NPS management of paleontological resources is detailed in Appendix C. Paleontological resource protection training is available for NPS staff through the NPS Paleontology Program. The Paleontology Program is also available to provide support in investigations involving paleontological resource theft or vandalism.

Between 2009 and 2022 an interagency coordination team including representatives from the Bureau of Land Management (BLM), Bureau of Reclamation (BOR), National Park Service (NPS) and U.S. Fish & Wildlife Service (FWS) developed the DOI final regulations for PRPA. In 2022, the DOI Paleontological Resources Preservation Act final regulation was published in the Federal Register and approved by the Office of Management and Budget. It is available at the following website: https://www.federalregister.gov/documents/2022/08/02/2022-16405/paleontological-resources-preservation. For more information regarding this act, visit https://www.nps.gov/subjects/fossils/fossil-protection.htm.

2006 National Park Service Management Policies (section 4.8.2.1) state

> *... Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).*
>
> *Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately*

documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.

The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.

All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

Fossils have scientific, aesthetic, cultural, educational, and tourism value, and impacts to any of these values impairs their usefulness. Effective paleontological resource management protects fossil resources by implementing strategies that mitigate, reduce, or eliminate loss of fossilized materials and their relevant data. Because fossils are representatives of adaptation, evolution, and diversity of life through deep time, they have intrinsic scientific values beyond just the physical objects themselves. Their geological and geospatial contexts provide additional critical data concerning paleoenvironmental, paleogeographic, paleoecologic, and a number of other conditions that together allow for a more complete interpretation of the physical and biological history of the earth. Therefore, paleontological resource management must act to protect not only the fossils themselves, but to collect and maintain other contextual data as well.

In general, losses of paleontological resources result from naturally occurring physical processes, by direct or indirect human activities, or by a combination of both. These processes or activities influence the stability and condition of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). The greatest loss of associated contextual data occurs when fossils are removed from their original geological context without appropriate documentation. Thus, when a fossil weathers and erodes from its surrounding sediments and geologic context, it begins to lose significant ancillary data until, at some point, it becomes more a scientific curiosity than a useful piece of scientific data. A piece of loose fossil "float" can still be of scientific value. However, when a fossil has been completely removed from its original context, such as an unlabeled personal souvenir or a specimen with no provenance information in a collection, it is of very limited scientific utility. Similarly, inadvertent exhumation of fossils during roadway construction or a building excavation may result in the loss or impairment of the scientific and educational values associated with those fossils. It is not necessary to list here all of the natural and anthropogenic factors that can lead to the loss of paleontological resources; rather, it is sufficient to acknowledge that anything that disturbs

native sediment or original bedrock has the potential to result in the loss of the paleontological resources that occur there or the loss of associated paleontological resource data.

Cave localities are in a distinct class for management due to the close connection with archeological resources and unique issues affecting cave resources. See Santucci et al. (2001) for additional discussion of paleontological resources in cave settings.

Management strategies to address any of these conditions and factors could also incorporate the assistance of qualified specialists to collect and document resources rather than relying solely on staff to accomplish such a large task at EFMO. Active recruitment of paleontological research scientists should also be used as a management strategy.

At this time, fossils at EFMO are protected by passive factors. Aside from the Platteville Formation fossils, examples are almost exclusively trace fossils of limited interest to collectors. Many of these trace fossils would not be recognized as fossils by the average visitor and would be firmly embedded in situ in bluff sides aside from the occasional fallen rock. The Platteville Formation fossils are recognizable as fossil shells and similar, but access is inconvenient. Furthermore, they are unremarkable for the Platteville Formation, and more convenient and legally accessible outcrops with material of comparable or superior quality are widely distributed in northeastern Iowa, southeastern Minnesota, and western Wisconsin. With these factors combined, systematic fossil theft is unlikely to be a significant resource concern at EFMO. Adventitious collecting of isolated specimens is possible, though, and it is certainly possible that a visitor may find a fossiliferous stone and bring it to the visitor center for identification. Modest publicity of the existence of fossils at EFMO is not expected to significantly alter these considerations, as any fossils that can be found at EFMO can be found more easily and in greater numbers outside of the monument. Improved trails beyond the current system would pose more of a risk. Expansion of EFMO poses uncertain consequences; it is likely that additional fossiliferous areas would be incorporated into the monument, but at this time, there does not appear to be any notable collecting localities in areas proposed for addition, per maps in the General Management Plan (National Park Service 2013).

Baseline Paleontology Resource Data Inventories

A baseline inventory of paleontological resources is critical for implementing effective management strategies, as it provides information for decision-making. This inventory report has compiled information on previous paleontological research done in and near EFMO, taxonomic groups that have been reported within EFMO boundaries, and localities that were previously reported. This report can serve as a baseline source of information for future research, inventory reports, monitoring, and paleontological decisions. The Paleontological Resource Inventory and Monitoring report for the Heartland I&M Network completed by Hunt et al. (2008) and the references cited within were important baseline paleontological resource data sources for this EFMO-specific report.

Paleontological Resource Monitoring

Paleontological resource monitoring is a significant part of paleontological resource management, and one which usually requires little to implement beyond time and equipment already on hand, such

as cameras and GPS units. Monitoring enables the evaluation of the condition and stability of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). A monitoring program revolves around periodic site visits to assess conditions compared to a baseline for that site, with the periodicity depending on factors such as site productivity, accessibility, and significance of management issues. For example, a highly productive site that is strongly affected by erosion or unauthorized collection, and which can be easily visited by park staff, would be scheduled for more frequent visits than a less productive or less threatened site.

A monitoring program is generally implemented after an inventory has been prepared for a park and sites of concern have been identified, with additional sites added as necessary. Because each park is different, with different geology and paleontology among other factors, ideally each park which has in situ fossils or significant accumulations of reworked fossils would have its own monitoring protocol to define its monitoring program. Data accumulated via monitoring is used to inform further management decisions, such as the following questions: Is the site suitable for interpretation and education? Does the site require stabilization from the elements? Is collection warranted? Is there a need for some form of law enforcement presence?

Collection is recommended to be reserved for fossils possessing exceptional value (e.g., rare or high scientific significance) or at immediate risk of major degradation or destruction by human activity and natural processes. Therefore, paleontological resource monitoring is a more feasible potential management tool. The first step in the establishment of a monitoring program is the identification of localities to be monitored, as discussed previously. Locality condition forms are then used to evaluate factors that could cause loss of paleontological resources, with various conditions at each locality rated as good, fair, or poor. Risks and conditions are categorized as Disturbance, Fragility, Abundance, and Site Access. “Disturbance” evaluates conditions that promote accelerated erosion or mass wasting resulting from human activities. “Fragility” evaluates natural conditions that may influence the degree to which fossil transportation is occurring. Sites with elevated fragility exhibit inherently soft rapidly eroding sediment or mass wasting on steep hillsides. A bedrock outcrop that is strongly lithified has low fragility. “Abundance” judges both the natural condition and number of specimens preserved at the locality as well as the probability of being recognized as a fossil-rich area by non-paleontologists, which could lead to unpermitted collecting. “Site Access” assesses the risk of a locality being visited by large numbers of visitors or the potential for easy removal of large quantities of fossils or fossil-bearing sediments. A locality with high access would be in close proximity to public use areas or other access (along trails, at roadcuts, at beach or river access points, and so on).

Each of the factors noted above may be mitigated by management actions. Localities exhibiting a significant degree of disturbance may require either active intervention to slow accelerated erosion, periodic collection and documentation of fossil materials, or both. Localities developed on sediments of high fragility naturally erode at a relatively rapid rate and would require frequent visits to document and/or collect exposed fossils in order to prevent or reduce losses. Localities with abundant or rare fossils, or high rates of erosion, may be considered for periodic monitoring in order to assess the stability and condition of the locality and resources, in regard to both natural processes and

human-related activities. Localities that are easily accessible by road or trail would benefit from the same management strategies as those with abundant fossils and by occasional visits by park staff, documentation of in situ specimens, and/or frequent law enforcement patrols. Further information on paleontological resource monitoring can be found in Santucci and Koch (2003) and Santucci et al. (2009).

Foundation Documents and Resource Stewardship Strategies

Foundation documents and Resource Stewardship Strategies are two types of park planning documents that may contain and reference paleontological resource information. A foundation document is intended to provide basic guidance about a park for planning and management. It briefly describes a given park and its purpose, significance, fundamental resources and values, other importance resources and values, and interpretive themes. Mandates and commitments are also identified, and the state of planning is assessed. Foundation documents may include paleontological information and are also useful as a preliminary assessment of what a park's staff know about their paleontological resources, the importance they place on these resources, and the present state of these non-renewable resources. A foundation document for EFMO has been published (National Park Service 2014).

A Resource Stewardship Strategy (RSS) is a strategic plan intended to help park managers achieve and maintain desired resource conditions over time. It offers specific information on the current state of resources and planning, management priorities, and management goals over various time frames. An RSS for EFMO is in progress as of 2024, with Tweet as a participant.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter indicating the age and lowercase letters indicating the formation's name. The American Geosciences Institute website (https://www.americangeosciences.org/environment/publications/mapping) provides more information about geologic maps and their uses. The NPS Geologic & Soils Resources Inventories (GSRI; historically the Geologic Resources Inventory, or GRI, which is used below) has been digitizing existing maps of NPS units and making them available to parks for resource management.

Geologic maps are one of the foundational elements of a paleontological resource management program. Knowing which sedimentary rocks and deposits underlie a park and where they are exposed are essential for understanding the distribution of known or potential paleontological resources. The ideal scale for resource management in the 48 contiguous states is 1:24,000 (maps for areas in Alaska tend to be coarser). Whenever possible, page-sized geologic maps derived from GRI files are included in paleontological resource inventory reports for reference, but it is recommended that GRI source files be downloaded from IRMA for use. The source files can be explored in much greater detail and incorporated into the park GIS database. Links to the maps digitized by the GRI for EFMO can be found in IRMA at https://irma.nps.gov/DataStore/Reference/Profile/2300332 and

https://irma.nps.gov/DataStore/Reference/Profile/2300333. In addition to a digital GIS geologic map, the GRI program also produces a park-specific report discussing the geologic setting, distinctive geologic features and processes within the park, highlighting geologic issues facing resource managers, and describing the geologic history leading to the present-day landscape of the park. A GRI report has not yet been prepared for EFMO, but a scoping report exists (Graham 2011).

Paleontological Resource Potential Maps

A paleontological resource potential map is included in this report (Figure 62). The map shows the distribution of geologic units within EFMO that are known to have yielded fossils within the monument (green) or have not yielded fossils within the monument but are fossiliferous elsewhere (yellow). This map gives a quick indication of areas where fossils may be discovered, which in turn can provide suggestions for areas to survey or monitor, or areas where the discovery of fossils may be of concern during work that disturbs the ground (road work, building construction, etc.). Only the North and South Units and Heritage Addition are included in Figure 62; the Sny Magill Unit was omitted because this unit has no bedrock outcrops.

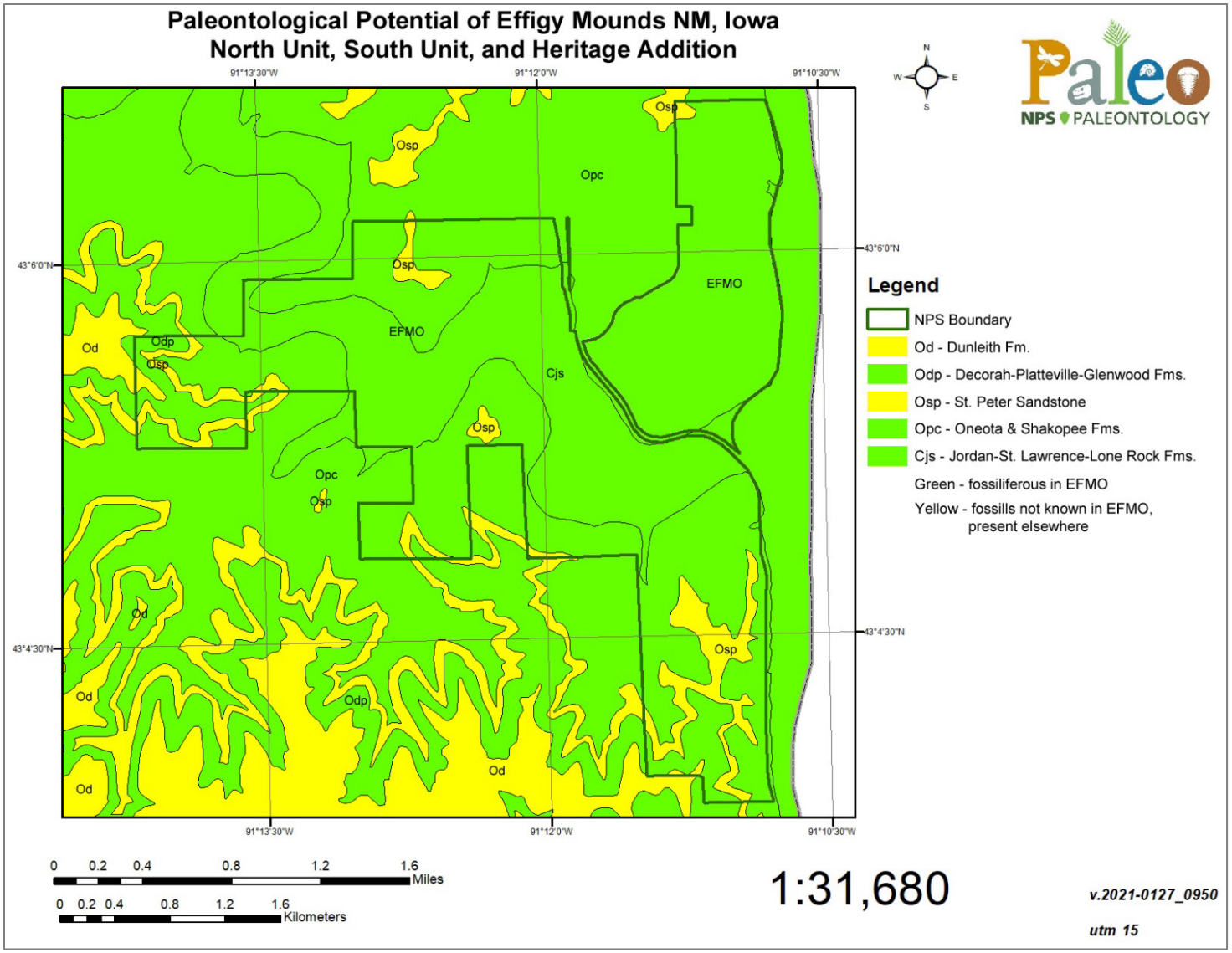


Figure 62. Map indicating paleontological potential of geologic map units in EFMO. Modified from Figure 6; units mapped as green have yielded fossils within EFMO, and units mapped as yellow have not yielded fossils in EFMO but have yielded fossils elsewhere.

Paleontological Resource Management Recommendations

The paleontological resource inventory at EFMO has documented rich and previously unrecognized paleontological resources. This report captures the scope, significance, and distribution of fossils at EFMO and provides recommendations to support the management and protection of the monument's non-renewable paleontological resources.

- EFMO staff should be encouraged to observe exposed rocks and sedimentary deposits for fossil material while conducting their usual duties. To promote this, staff should receive guidance regarding how to recognize common local fossils. When opportunities arise to observe paleontological resources in the field and take part in paleontological field studies with trained paleontologists, staff should take advantage of them if funding and time permit.
- EFMO staff should photo-document and monitor any occurrences of paleontological resources that may be observed in situ. Fossils and their associated geologic context (surrounding rock) should be documented but left in place unless they are subject to imminent degradation. A Geologic Resource Monitoring Manual published by the Geological Society of America and NPS Geologic Resources Division (GRD) includes a chapter on paleontological resource monitoring (Santucci et al. 2009). Santucci and Koch (2003) also present information on paleontological resource monitoring.
- Fossil theft is one of the greatest threats to the preservation of paleontological resources and any methods to minimize these activities should be utilized by staff. Any occurrence of paleontological resource theft or vandalism should be investigated by a law enforcement ranger. When possible, incidents should be fully documented and the information submitted for inclusion in the annual law enforcement statistics.
- Fossils found in a cultural context should be documented like other fossils but will also require the input of an archeologist or a cultural resource specialist. Any fossil which has a cultural context may be culturally sensitive as well (e.g., subject to NAGPRA) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material.
- EFMO should consult with affiliated tribes to learn if there are any interpretations, beliefs, or other cultural aspects to the monument's fossils.
- Assessing the cultural landscape of EFMO from a geological point of view also has merit. For example, there is interest from staff about learning about recognizing human modification to geological exposures to distinguish them from natural erosion (S. Oberreuter, pers. comm., 6 September 2024). This has a bearing on recognizing sites as quarries. A project could also be undertaken to look at the incidence of fossils at quarry sites, whether they are present in chert debitage, and whether they are present in chert artifacts.
- The monument may fund and recruit paleontology interns as a cost-effective means of enabling some level of paleontological resource support. The Scientists in Parks Program is an established program for recruitment of geology and paleontology interns. Alternatively,

some projects may be appropriate for local college students or volunteers, depending on scope. For example, a volunteer familiar with local fossils could easily handle the site monitoring described above, or a student with a background in fossils and museums could assist with issues in the Orr collection.

- Consideration should be given to fossil management if trails are developed in fossiliferous areas.
- Exposures of stromatolites in situ in the Prairie du Chien Group may be of interest for interpretation if the location is safe for visitors. Many of the Prairie du Chien Group outcrops in the monument are too steep for safe access, but a rockfall may produce a block or blocks that can be transported to a suitable location for interpretation.
- If any areas are added to EFMO, they should be assessed for paleontological resources.
- The curatorial and data issues cited for the Orr collection should be addressed, perhaps in stages. It will likely be necessary to consult or collaborate with the University of Iowa, Luther College, and perhaps other institutions.
- EFMO, MISS, and SACN are strongly linked by paleontology and bedrock geology, and none of the three have large staffs. It is recommended that staff at the three units consider sharing concerns, ideas, and solutions for interpretation and resource management for these resource categories.
- Contact the NPS Paleontology Program for technical assistance with paleontological resource management issues.

If fossil specimens are found by EFMO staff, it is recommended they follow the steps outlined below to ensure proper paleontological resource management.

- Photo-document the specimen without moving it from its location, if it is loose. Include a common item, such as a coin, pen, or pencil, for scale if a ruler or scale bar is not available.
- If a GPS unit is available, record the location of the specimen. If GPS is not available, record the general location within EFMO and height within the outcrop, if applicable. If possible, revisit the site when a GPS unit is available. Most smartphones also have the ability to record coordinates; if no GPS unit is available, attempt to record the coordinates with a phone.
- Write down associated data, such as rock type, general description of the fossil, type of fossil if identifiable, general location in EFMO, sketch of the fossil, position within the outcrop or if it is loose on the ground, any associated fossils, and any other additional information.
- Do not remove the fossil unless it is loose in an area of heavy traffic, such as a public trail, and is at risk of being taken or destroyed. If the fossil is removed, be sure to wrap in soft material, such as tissue paper, and place in a labeled plastic bag with associated notes. Because EFMO has many culturally important sites, simply documenting the fossil and leaving it in place is the best course of action until natural resource staff is contacted.

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Appendix A: Paleontological Species

The following section presents lists of paleontological taxa for each geologic unit known to be fossiliferous within EFMO: the Jordan Formation, Prairie du Chien Group, Platteville Formation, and Quaternary sediments. The lists are organized by taxonomic groups. References are included in parentheses where they exist; otherwise, the taxon was recorded from the lead author's field inventory. The term "sp." indicates a taxon that is thought to belong to a certain genus, but the species or has not been determined; "isp." is used similarly for trace fossils (ichnotaxa). The term "cf." indicates a similarity to a certain taxon.

Jordan Formation Taxa

Ichnofossils:

- Possible stromatolites (McKay 1993)
- *Skolithos* isp. (McKay 1993)
- Undetermined invertebrate burrows/trails and bioturbation (McKay 1993; also observed)

Prairie du Chien Group Taxa

Invertebrata: Mollusca: Gastropoda:

- "*Euomphalus*" (Shumard 1852)
- "*Natica*" (Shumard 1852)
- Gastropoda undetermined

Invertebrata undetermined:

- Undetermined shells
- Undetermined ringed structure

Ichnofossils:

- Stromatolites (McKay 1993; also observed)
- *Skolithos* isp. (McKay 1993)
- Undetermined invertebrate burrows/trails

Platteville Formation Taxa

Invertebrata: Cnidaria: Anthozoa: Hexacorallia: Rugosa:

- Rugosa undetermined (horn corals)

Invertebrata: Bryozoa:

- Bryozoa undetermined (stem-like)
- Bryozoa undetermined (mesh-like)

Invertebrata: Brachiopoda:

- *Camerella* sp.
- *Doleroides* sp.
- *Hesperorthis* sp.
- *Oepikina*?
- *Rostricellula* sp.
- *Sowerbyella* sp.
- *Strophomena* sp.
- Orthida undetermined
- Strophomenida undetermined
- Brachiopoda undetermined

Invertebrata: Mollusca: Bivalvia

- Cyrtodontida undetermined
- Bivalvia undetermined

Invertebrata: Mollusca: Cephalopoda: Nautiloidea:

- *Anaspyroceras* cf. *A. lesueuri*
- Nautiloidea undetermined (small orthoconic form)
- Nautiloidea undetermined (cyrtoconic or gyroconic form)

Invertebrata: Mollusca: Gastropoda

- *Clathrospira* sp.
- *Hormotoma* sp.
- *Ophiletina*?
- cf. *Subulites*?
- Bellerophontida undetermined
- Gastropoda indetermined (planispiral or pseudoplanispiral)
- Gastropoda undetermined

Invertebrata: Arthropoda: Trilobita:

- Pterygometopidae undetermined
- Trilobita undetermined (at least one taxon, with large genal spines)

Invertebrata: Arthropoda: Ostracoda:

- *Eoleperditia fabulites*

Invertebrata: Echinodermata: Crinoidea:

- cf. *Abludoglyptocrinus* columnals (ridge-waisted columnals)
- Crinoidea undetermined (typical circular or gear-like columnals, potentially multiple taxa)
- Crinoidea undetermined (five-lobed "floral" columnals)
- Crinoidea undetermined (pentagonal columnals)

Invertebrata: Hyolithida:

- Hyolithida undetermined

Invertebrata:

- Undetermined doubly curved annulated fossil
- Invertebrata undetermined

Ichnofossils:

- Undetermined invertebrate burrows/trails

Holocene Taxa

All taxa are after McGuire Bogen and Hotchkiss (2007).

Plantae: "Pteridophyta":

- Trilete spores, representing ferns and allies (spores)

Plantae: Lycopodiopsida: Lycopodiaceae:

- *Lycopodium* (clubmoss) (spores)

Plantae: Lycopodiopsida: Selaginellaceae:

- *Selaginella* (spikemoss) (spores)

Plantae: Coniferae: Pinaceae:

- *Picea* (spruce) (pollen)
- *Pinus* "diplox" (pollen, red pine type)
- *Pinus* "haplox" (pollen, white pine type)
- *Pinus* undifferentiated (pine) (pollen)
- *Tsuga* (hemlock) (pollen)

Plantae: Angiospermae: Adoxaceae:

- *Sambucus* (elder) (pollen)

Plantae: Angiospermae: Alismataceae:

- *Sagittaria* (pollen)

Plantae: Angiospermae: Amaranthaceae:

- Chenopodiaceae/Amaranthaceae (various herbs/shrubs) (pollen)

Plantae: Angiospermae: Apiaceae:

- Apiaceae (celery) (pollen)

Plantae: Angiospermae: Araceae:

- *Lemna* (duckweed) (pollen)

Plantae: Angiospermae: Asteraceae:

- *Ambrosia* (ragweed) (pollen)
- *Artemisia* (pollen)
- *Solidago* (goldenrod) (pollen)
- Asteraceae, subfamily Tubuliflorae, long-spined (pollen)
- Asteraceae, subfamily Tubuliflorae, short-spined (pollen)
- Asteraceae, subfamily Liguliflorae (pollen)

Plantae: Angiospermae: Betulaceae:

- *Alnus* (alder) (pollen)
- *Betula* (birch) (pollen)
- *Corylus* (hazel) (pollen)
- *Ostrya-Carpinus* (hophornbeam-hornbeam) (pollen)

Plantae: Angiospermae: Caryophyllaceae:

- Caryophyllaceae (carnation) (pollen)

Plantae: Angiospermae: Cyperaceae:

- Cyperaceae (sedges) (pollen)

Plantae: Angiospermae: Fagaceae:

- *Quercus* (oak) (pollen)

Plantae: Angiospermae: Juglandaceae:

- *Carya* (hickory) (pollen)
- *Juglans* (walnut) (pollen)

Plantae: Angiospermae: Malvaceae:

- *Tilia* (basswood) (pollen)

Plantae: Angiospermae: Oleaceae:

- *Fraxinus* (ash) (pollen)

Plantae: Angiospermae: Plantaginaceae:

- *Plantago* (plantain) (pollen)

Plantae: Angiospermae: Poaceae:

- Poaceae (grasses) (pollen)

Plantae: Angiospermae: Polygonaceae:

- *Rumex* (docks and sorrels) (pollen)

Plantae: Angiospermae: Potamogetonaceae:

- *Potamogeton* (pondweed) (pollen)

Plantae: Angiospermae: Rubiaceae:

- *Galium* (bedstraw) (pollen)

Plantae: Angiospermae: Salicaceae:

- *Salix* (willow) (pollen)

Plantae: Angiospermae: Sapindaceae:

- *Acer* (maple) (pollen)

Plantae: Angiospermae: Ulmaceae:

- *Ulmus* (elm) (pollen)

Plantae:

- Plantae undetermined (charcoal, peat, seeds, woody fragments)

Invertebrata: Mollusca: Gastropoda:

- Gastropoda undetermined

Invertebrata:

- Undetermined shells

Other fossils:

- Unspecified algae
- Diatoms (elongate)

Appendix B: Repository Contact Information

Contact information for institutions known to have collections from EFMO are included below. Addresses, links, and email addresses to departments are included as available. This information is subject to change, particularly hyperlinks.

CONTINENTAL SCIENTIFIC DRILLING FACILITY
116 Church Street SE
Minneapolis, MN 55455
(612) 626-7889
https://cse.umn.edu/csd
csdfacility@umn.edu

This repository (formerly LacCore) includes the Founders Pond core studied by McGuire Bogen and Hotchkiss.

LUTHER COLLEGE
700 College Drive
Decorah, IA 52101
(563) 387-2000
https://www.luther.edu/

The geology collection here is in the Environmental Studies wing of Valders Hall of Science.

UNIVERSITY OF IOWA PALEONTOLOGY REPOSITORY
Department of Geoscience
University of Iowa
121 Trowbridge Hall, Iowa City, IA
(319) 335-1822

The Orr collection at this repository was transferred to EFMO with the exception of published specimens.

Strictly speaking, the relevant fossils at Luther College and the University of Iowa are from Ellison Orr's collection and are therefore unlikely to have been found within EFMO. They are included here to account for other known repositories of portions of Orr's paleontological collection. It is possible that other institutions have small numbers of fossils collected by Orr, obtained by trade or donation. It is also possible that some of the fossils in the Keyes collection at the Iowa Office of the State Archaeologist were found by Orr.

Appendix C: Paleontological Resource Law and Policy

The following material is reproduced in large part from Henkel et al. (2015); see also Kottkamp et al. (2020).

In March 2009, the Paleontological Resources Preservation Act (PRPA) (16 USC 460aaa) was signed into law (Public Law 111–11). This act defines paleontological resources as

> *... any fossilized remains, traces, or imprints of organisms, preserved in or on the [E]arth's crust, that are of paleontological interest and that provide information about the history of life on [E]arth.*

The law stipulates that the Secretary of the Interior should manage and protect paleontological resources using scientific principles. The Secretary should also develop plans for

> *... inventory, monitoring, and deriving the scientific and educational use of paleontological resources.*

Paleontological resources are considered park resources and values that are subject to the "no impairment" standard in the National Park Service Organic Act (1916). In addition to the Organic Act, PRPA will serve as a primary authority for the management, protection, and interpretation of paleontological resources. The proper management and preservation of these non-renewable resources should be considered by park resource managers whether or not fossil resources are specifically identified in the park's enabling legislation.

The Paleontological Resources Management section of NPS Reference Manual 77 provides guidance on the implementation and continuation of paleontological resource management programs. Administrative options include those listed below and a park management program will probably incorporate multiple options depending on specific circumstances:

- **No action**—no action would be taken to collect the fossils as they erode from the strata. The fossils would be left to erode naturally and over time crumble away, or possibly be vandalized by visitors, either intentionally or unintentionally. This is the least preferable plan of action of those listed here.
- **Surveys**—will be set up to document potential fossil localities. All sites will be documented with the use of GPS and will be entered into the park GIS database. Associated stratigraphic and depositional environment information will be collected for each locality. A preliminary fossil list will be developed. Any evidence of poaching activity will be recorded. Rates of erosion will be estimated for the site and a monitoring schedule will be developed based upon this information. A NPS Paleontological Locality Database Form will also be completed for each locality. A standard version of this form will be provided by the Paleontology Program of the Geologic Resources Division upon request and can be modified to account for local conditions and needs.

- **Monitoring**—fossil-rich areas would be examined periodically to determine if conditions have changed to such an extent that additional management actions are warranted. Photographic records should be kept so that changes can be more easily ascertained.
- **Cyclic prospecting**—areas of high erosion which also have a high potential for producing significant specimens would be examined periodically for new sites. The periodicity of such cyclic prospecting will depend on locality-specific characteristics such as rates of sediment erosion, abundance or rarity of fossils, and proximity to visitor use areas.
- **Stabilization and reburial**—significant specimens which cannot be immediately collected may be stabilized using appropriate consolidants and reburied. Reburial slows down but does not stop the destruction of a fossil by erosion. Therefore, this method would be used only as an interim and temporary stop-gap measure. In some situations, stabilization of a locality may require the consideration of vegetation. For example, roots can destroy in situ fossils, but can also protect against slope erosion, while plant growth can effectively obscure localities, which can be positive or negative depending on how park staff want to manage a locality.
- **Shelter construction**—it may be appropriate to exhibit certain fossil sites or specimens in situ, which would require the construction of protective shelters to protect them from the natural forces of weathering and erosion. The use of shelters draws attention to the fossils and increases the risk of vandalism or theft, but also provides opportunities for interpretation and education.
- **Excavation**—partial or complete removal of any or all fossils present on the surface and potentially the removal of specimens still beneath the surface which have not been exposed by erosion.
- **Closure**—the area containing fossils may be temporarily or permanently closed to the public to protect the fossil resources. Fossil-rich areas may be closed to the public unless accompanied by an interpretive ranger on a guided hike.
- **Patrols**—may be increased in areas of known fossil resources. Patrols can prevent and/or reduce theft and vandalism. The scientific community and the public expect the NPS to protect its paleontological resources from vandalism and theft. In some situations, a volunteer site stewardship program may be appropriate (for example the “Paleo Protectors” at Chesapeake & Ohio Canal National Historical Park).
- **Alarm systems/electronic surveillance**—seismic monitoring systems can be installed to alert rangers of disturbances to sensitive paleontological sites. Once the alarm is engaged, a ranger can be dispatched to investigate. Motion-activated cameras may also be mounted to visually document human activity in areas of vulnerable paleontological sites.

National Park Service Management Policies (2006; Section 4.8.2.1) also require that paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. In 2010, the National Park Service established National Fossil Day as a celebration and partnership organized to

promote public awareness and stewardship of fossils, as well as to foster a greater appreciation of their scientific and educational value (https://www.nps.gov/subjects/fossilday/index.htm). National Fossil Day occurs annually on Wednesday of the second full week in each October in conjunction with Earth Science Week.

Related Laws, Legislation, and Management Guidelines

National Park Service Organic Act

The NPS Organic Act directs the NPS to manage units

> *... to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner as will leave them unimpaired for the enjoyment of future generations. (16 U.S.C. § 1).*

Congress reiterated this mandate in the Redwood National Park Expansion Act of 1978 by stating that the NPS must conduct its actions in a manner that will ensure no

> *... derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress. (16 U.S.C. § 1 a-1).*

The Organic Act prohibits actions that permanently impair park resources unless a law directly and specifically allows for the acts. An action constitutes an impairment when its impacts

> *... harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources and values. (Management Policies 2006 1.4.3).*

Paleontological Resources Protection Act (P.L. 111-011, Omnibus Public Land Management Act of 2009, Subtitle D)

Section 6302 states

> *The Secretary (of the Interior) shall manage and protect paleontological resources on Federal land using scientific principles and expertise. The Secretary shall develop appropriate plans for inventory, monitoring, and the scientific and educational use of paleontological resources, in accordance with applicable agency laws, regulations, and policies. These plans shall emphasize interagency coordination and collaborative efforts where possible with non-Federal partners, the scientific community, and the general public.*

Federal Cave Resources Protection Act of 1988 (16 USC 4301)

This law provides a legal authority for the protection of all cave resources on NPS and other federal lands. The definition for “Cave Resource” in Section 4302 states

Cave resources include any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems.

NPS Management Policies 2006

NPS Management Policies 2006 include direction for preserving and protecting cultural resources, natural resources, processes, systems, and values (National Park Service 2006). It is the goal of the NPS to avoid or minimize potential impacts to resources to the greatest extent practicable consistent with the management policies. The following is taken from section 4.8.2.1 of the NPS Management Policies 2006, "Paleontological Resources and their contexts":

Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).

Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.

The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.

Parks will exchange fossil specimens only with other museums and public institutions that are dedicated to the preservation and interpretation of natural heritage and qualified to manage museum collections. Fossils to be deaccessioned in an exchange must fall outside the park's scope of collection statement. Systematically collected fossils in an NPS museum collection in compliance with 36 CFR 2.5 cannot be outside the scope of the collection statement. Exchanges must follow deaccession procedures in the Museum Handbook, Part II, chapter 6.

The sale of original paleontological specimens is prohibited in parks.

The Service generally will avoid purchasing fossil specimens. Casts or replicas should be acquired instead. A park may purchase fossil specimens for the park museum collection only after making a written determination that

- *The specimens are scientifically significant and accompanied by detailed locality data and pertinent contextual data;*
- *The specimens were legally removed from their site of origin, and all transfers of ownership have been legal;*
- *The preparation of the specimens meets professional standards;*
- *The alternatives for making these specimens available to science and the public are unlikely;*
- *Acquisition is consistent with the park's enabling legislation and scope of collection statement, and acquisition will ensure the specimens' availability in perpetuity for public education and scientific research.*

All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

(See Natural Resource Information 4.1.2; Studies and Collections 4.2; Independent Research 5.1.2; and Artifacts and Specimens 10.2.4.6 in NPS 2006, available here. Also see 36 CFR 2.5.)

NPS Director's Order-77, Paleontological Resources Management

DO-77 describes fossils as non-renewable resources and identifies the two major types, body fossils and trace fossils. It describes the need for managers to identify potential paleontological resources using literature and collection surveys, identify areas with potential for significant paleontological resources, and conduct paleontological surveys (inventory). It also describes appropriate actions for managing paleontological resources including: no action, monitoring, cyclic prospecting, stabilization and reburial, construction of protective structures, excavation, area closures, patrols, and the need to maintain confidentiality of sensitive location information.

Excerpt from Clites and Santucci (2012):

Monitoring

An important aspect of paleontological resource management is establishing a long-term paleontological resource monitoring program. National Park Service paleontological resource monitoring strategies were developed by Santucci et al. (2009). The park's monitoring program should incorporate the measurement and evaluation of the factors stated below.

Climatological Data Assessments
These assessments include measurements of factors such as annual and storm precipitation, freeze/thaw index (number of 24-hour periods per year where temperature fluctuates above and below 32 degrees Fahrenheit), relative humidity, and peak hourly wind speeds.

Rates of Erosion Studies
These studies require evaluation of lithology, slope degree, percent vegetation cover, and rates of denudation around established benchmarks. If a park does not have this information, there may be opportunities to set up joint projects, because erosion affects more than just paleontological resources.

Assessment of Human Activities, Behaviors, and Other Variables
These assessments involve determining access/proximity of paleontological resources to visitor use areas, annual visitor use, documented cases of theft/vandalism, commercial market value of the fossils, and amount of published material on the fossils.

Condition Assessment and Cyclic Prospecting
These monitoring methods entail visits to the locality to observe physical changes in the rocks and fossils, including the number of specimens lost and gained at the surface exposure. Paleontological prospecting would be especially beneficial during construction projects or road repair.

Periodic Photographic Monitoring
Maintaining photographic archives and continuing to photo-document fossil localities from established photo-points enables visual comparison of long-term changes in site variables.

Appendix D: Geologic Time Scale

A geologic time scale (Figure 63) is provided below for reference.

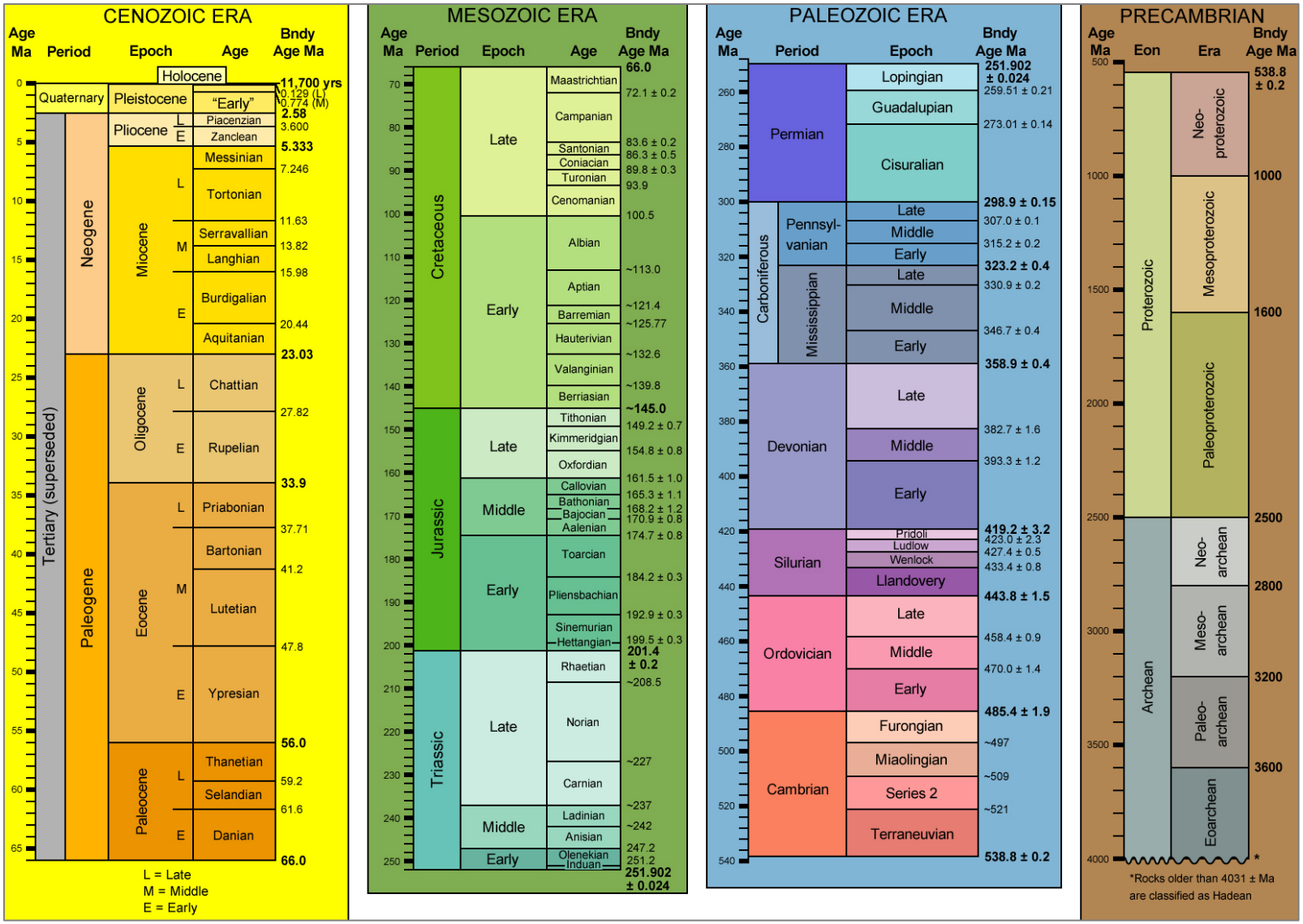


Figure 63. Geologic time scale. **Ma**=Millions of years old. **Bndy Age**=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://rock.geosociety.org/net/documents/gsa/timescale/timescl-1999.pdf). Dates after International Commission on Stratigraphy version 2023/09. NPS / JUSTIN TWEET

National Park Service
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